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STUDY OF STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS
REPORT

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17. Abstract

The objective of the project was to define and study in detail the factors and design criteria affecting ice-going propeller nozzle strength requirements and to formulate general analytical expressions which, when calibrated, could be used for design and regulatory purposes.

The major effort in the study of nozzle strength was the development of an analytical model. Bottom, side and axial loading cases were investigated for a ring structure. Bending and torsional moments, shear and tangential forces and deflections were calculated around the ring. In addition the foundation reactions and the effect of load spread were determined. The applicability of these results to a three-dimensional case was confirmed by finite element modelling.

The study concluded by suggesting requirements for regulatory body consideration and by proposing a full-scale test program.

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17. Résumé

L'objectif de ce programme était de définir et d'approfondir les facteurs et les critères de calcul concernant la résistance à donner aux tuyères protégeant les hélices des navires naviguant dans les glaces, et d'établir des équations d'application générale visant à faciliter les fonctions de calcul et de réglementation.

L'objectif principal de la présente recherche a été la formulation d'un modèle tenant compte des régimes de charge s'exerçant dans les trois axes d'une structure annulaire. Les moments de flexion et de torsion, les efforts de cisaillement et les forces tangentielles, ainsi que les déformations correspondantes ont été calculés. En outre, les réactions dans le carlingage ainsi que l'effet de la répartition des charges ont été déterminés. Enfin, l'applicabilité du modèle formulé à une structure tridimensionnelle a été confirmée par la méthode des éléments finis.

Le rapport termine par des suggestions concernant les critères de réglementation et en préconisant un programme d'essais en vraie grandeur.

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EXECUTIVE SUMMARY

Project objective was:

To define and study in detail the factors and design criteria affecting ice going propeller nozzle strength requirements and to formulate general analytical expressions which, when calibrated, can be used for design and regulatory purposes.

In order to achieve this objective, the following work was done:

1. Review of the State-of-the-Art

   A bibliography search identified only a few papers dealing with the strength of nozzles under hydrodynamic loading. Only Lloyd's Register of Shipping offers guidelines for nozzles of low powered ships. Yet the number of icebreaking ships outfitted with shrouded propellers is steadily growing. In the Canadian Arctic 12 ships have shrouded propellers. The largest nozzles are fitted to the M.V. Arctic (5.4 m diameter and 14,800 bhp) and the M.V. Kigoriak (5.33 m diameter and 16,800 bhp). As calculated in this study the nozzle of the Kigoriak can withstand loads of up to 1,400 tonnes radially and 3,200 tonnes axially, before reaching yield.

2. Range of Ships and Powers Involved

   2 m, 4 m, 6 m, and 8 m diameter nozzles were selected to cover the whole range of present and future applications. The 8 m diameter nozzle was chosen for each shaft on a twin shaft icebreaking tanker with a total horsepower of 100,000 and a displacement of 300,000 tonnes. Based on current design trends the relationship between horsepower and the disk area of shrouded propellers was established as:

   Disk Area $\cong (HP)^{0.88}/232$, where disk area is in m^2,

or

   Disk Area $\cong (KW)^{0.88}/177$ if power is in kilowatts.

3. Basic nozzle geometry, locations and attachments.

Nozzles are rings made of airfoil type sections. Most of the nozzles have the following characteristics:

Nozzle Length/Dia	$0.5 < \ell/D < 0.8$
Profile Thickness/Lengths	$0.07 < s/P < 0.19$
Entrance Angle	$10.2° < \alpha_i < 15.2°$
Camber	$0.03 < f < 0.07$

The most commonly used nozzles are NSMB #19A and #37, which have simplified shapes.

Structurally nozzles are composed of:

- inner and outer plating, with supporting stiffeners,
- rings webs,
- girders,
- upper/lower foundation,
- leading/trailing edge structure (pipe/castings).

The upper limit for the section moduli (Z) of the existing nozzles can be expressed as:

$$Z\ (cm^3) = 1000 * D^{2.35}\ (m)$$

The upper foundation angle Θ (defined as one half the angle over which the nozzle is attached at its upper surface to the ship's structure) varies between 8° (Arctic) and 90° (Robert LeMeur).

4. Range of Ice Features

Bergy bits, growlers, multi-year ridges and first year ice were features identified as potentially interacting with nozzles. The first three were considered to have low mobility and to have a representative "upper bound" crushing strength of 5 MPa. These features can be positioned on the side or the bottom of the nozzle.

5. Interaction Scenarios

Three scenarios have been identified:

- grounding on ice,
- swaying into ice, and
- ramming ice

Simple dimensional analysis has been shown to be inadequate to predict the range of ice impact induced forces. A computerized ship-ice interaction simulator (ICESIM) was run for a limited number of ice/ship interaction scenarios on two ships (30,000 tonnes and 300,000 tonnes displacement) with different nozzle sizes and differing nozzle locations on the smaller vessel. The main conclusions are:

- The magnitude of the maximum ice force increases with increasing ship displacement.
- The magnitude of the maximum ice force increases with increasing ice crushing strength.
- Due to the central location of a single shaft nozzle, the vessel's rolling response to a load is not as great as the response of a ship with twin shaft nozzles in a similar ship/ice interaction. Single shaft nozzles can therefore generate a higher force than twin shaft nozzles when installed on vessels of similar displacement. However due to the more protected location of a single centreline nozzle, the loads are expected to be lower than on a ship with twin nozzles.
- Side impacts generate higher forces than bottom impacts.

6. Analytical Model

Analytical modelling was selected as being most suitable for the general investigation of nozzle strengths. A series of nozzles was designed covering the whole range of possible applications. The basic nozzle shape selected was NSMB #37. Three (3) different profile thickness/nozzle length ratios were established:

$s/\ell = 0.2$
$s/\ell = 0.23$
$s/\ell = 0.26$

An investigation of the influence of s/ℓ on the hydrodynamic performance was performed. No significant deterioration of nozzle-propeller performance was found with increasing nozzle thickness.

The influence of shear and hoop force on the deformations of the nozzle ring were found to be small. Consequently, a thin-curved-beam theory was applied to solve for the following as a function of nozzle geometry, and applied load:

- bending moments,
- shear forces,
- hoop forces,
- deflections.

Two "base" cases were investigated in detail:

- side impact, and
- bottom impact.

For unit loads, an infinitely stiff top foundation, no bottom foundation, and equal inner and outer plating thicknesses, the principle findings were:

- Side impacts produce more severe stresses than bottom impacts.

- Maximum stresses in the nozzle occur at that side of the foundation which is nearest to the load application point.

- Bending moment stresses are larger than those due to shear and hoop stresses.

- The highest stresses occur in the inner ring plating. These stresses are compressive.

- When the nozzle is stressed to yield, the nozzle ring deflections lie within acceptable limits (1% of nozzle radius).

- Increase of foundation angle reduces the bending stresses significantly.

- Spreading of the load around the perimeter does not significantly reduce the maximum bending stresses, when compared to the stresses from an equivalent concentrated load.

- The highest stresses were caused by a load application at 105° measured from bottom centre. These stresses did not vary significantly for foundation angles from 0° to 20°.

- A unit axial load was found to produce much lower stresses than a unit radial load.

- Two expressions have been developed to estimate the force (F_{max}) in tonnes which causes yielding of the inner ring plating at the foundation. If the nozzle structure has been designed and the section modules is known, then the following expression can be used:

$$F_{max} = Z * \sigma_y/(R * 1.04 (.645 - (\theta°/213))$$

Where:

Z = the section modulus of nozzle
R = the mean radius of the nozzle
$\theta°$ = the foundation 1/2 angle ($\theta \leq 90°$)
σ_y = the yield strength of the material

At the preliminary design stage, only general nozzle particulars may be known and the following expression can be used:

$$F_{max} = D*t_{pl}*\sigma_y*(471/(137 - \theta°))*((\ell/D)/(1+D/s))$$

Where:
t_{pl} = the plating thickness of the ring (assumed constant)
ℓ = the length of the profile
D = the diameter of the nozzle
s = the profile thickness.

All units must be consistent.

- A brief assessment of nozzle's vibratory behaviour has shown no danger of resonance with blade-force vibrations.

- A brief assessment of buckling strength of the nozzle has shown no danger of buckling of nozzles structure.

7. FEM Model

A FEM model of a 6 m diameter nozzle and its foundation was constructed. The variation of key parameters in several runs leads to the following conclusions:

- The analytical model based on thin curved beam theory compares well with the FEM predictions for the bending moments, shear forces and tangential forces everywhere in the ring except at the foundation. The reduction of bending moment at that point in the FEM model is of the order of 10%.

- Neither the thickness of the profile nor the radius of the nozzle were found to influence the bending moment coefficients (expressed as the bending moment (BM) divided by the product of the applied force (F) and the radius of the nozzle (R) [C_{BM} = BM/(F * R)]).

- Deflections of the nozzle ring were found to be significantly larger than those predicted by the analytical model, due to the influence of foundation deformation and local plating deformations.

8. Suggested Regulatory Requirements

a) Global Strength

Two parallel approaches are recommended:

Design to Minimum Force

Where a designer has complete freedom in choosing the shape and scantlings of nozzle, the only requirement is that the nozzle must be able to withstand an ice force, being expressed as:

$$(F)_{ice} = K_1 * K_2 * (\Delta HP)^{\beta}$$

Where:

K_1 = nozzle location factor,

K_2 = ice class factor,

Δ = the displacement of the ship, in tonnes x 10^{-3}

$(F)_{ice}$ = design ice force, in tonnes.

HP = rated horsepower x 10^{-3} (all shafts)

Tentative values, subject to the future full scale calibration are:

K_1 = 1 for single shaft ships

K_1 = 1.2 for twin shaft ships

If megawatts are used in above formula, then:

K_1 = 1.04 for single shaft ships; and

K_1 = 1.25 for twin shaft ships.

Tentative values of K_2 are calculated from the following equation:

$K_2 = 100 + 60 * \text{ICE CLASS (ASPPR)}$

Coefficient β is tentatively set at 0.137 and is also the subject of future calibration.

Examples of the value of F_{ice}, in tonnes, are given in the following table:

ICE CLASS 2

	Δ				
HP	2,000	4,000	10,000	20,000	30,000
5,000	301	332	376	413	437
10,000	332	365	413	454	480
15,000	350	385	437	481	508
20,000	365	401	455	500	528

ICE CLASS 10

	Δ			
HP	30,000	60,000	90,000	300,000
30,000	1,777	1,955	2,066	2,437
60,000	1,955	2,150	2,272	2,680
90,000	2,066	2,272	2,402	2,833

Design to Required Strength Parameters

1. Minimum global strength section modulus is:

$$Z \geq K * F_{ice} * R * 1.04 * (0.645 - \theta/213°)/\sigma_y$$

Where:

Z	is the section modulus, expressed in cm^3,
K	is the safety factor, tentatively set at 1.0,
F_{ice}	is the ice force, defined as above,
θ°	is the foundation 1/2 angle, in degrees,
σ_y	is the yield strength of the material in $tonnes/cm^2$,
R	is the effective nozzle radius, in cm measured from the shaft centreline to the midweight of the profile.

2. For steels having $\sigma_y \leq 360$ MPa no special considerations have to be given to the deflections of the nozzle ring. For higher yield strength steels, the minimum required inertia of the cross-section is:

$I_{min} \geq * 22.8 * F_{ice} * R^3/ER_o$

R_o is the radius of the inner plating in cm, E is the elastic modulus of the steel (GN/m^2) and I_{min} is expressed in cm^4.

The above formulation is used for $\Theta = 15°$. For other values of Θ, see Chapter 8 of Volume 1.

3. The minimum required shear area in the radial direction is:

$A_{shear} \geq 0.9 * F_{ice}/\tau$

4. shear area of the nozzle attachment to the foundation in the axial direction should not be less than that calculated from the formula:

$(A_{shear})_{axial} > F_{ice}/\tau$

This formulation incorporates a safety factor of 2. Where possible, the area should be equally distributed between the upper and lower foundations.

b) Local Strength

Outer plating and stiffeners should be calculated using

the ice pressures for the stern, multiplied by a safety factor:

$P_{nozzle} = 1.5 * P_{stern}$

Foundation Support

The nozzle should be attached at the top and bottom to the stern structure. Unless the bottom support is substantial, it should only be included in the assessment of nozzle strength when subject to an axial load.

The stiffness of the foundation should be such as to limit the foundation induced displacements of the ring. Subject to further investigation of the effects of foundation stiffness, these foundation induced displacements should be limited to 25% of the total ring displacement for side impacts.

9. Planning of the Full Scale Tests to Calibrate the Analytical Model.

A comprehensive research program is proposed in order to quantify the following expression for one ship:

$$F_{max} = K_1 * K_2 (\Delta \text{ HP})^{\beta}$$

It was felt that satisfactory instrumentation of an existing nozzle would be extremely difficult and expensive. A test program has been developed for a new ship with a high ice class (at least Class 4). The program would include the following steps:

- Design of the nozzle to the requirements of the proposed regulations.
- FEM modelling of the nozzle and foundation to understand the structural response to various loading locations and to determine the instrumentation location.
- Ship instrumentation and calibration.
- Full scale trials.
- Data analysis.

10. Computer Programs

A series of programs were developed enabling any user to assess the strength of the designed nozzle.

Programs calculate:

Bending moments, shear forces, tangential forces, foundation reactions for any nozzle and direction of load application. A point or distributed load can be used.

Strength of any nozzle can be assessed by inputing actual structural properties of the nozzle.

11. Recommendations

Based on the present study the recommended procedure for calculating any nozzle's strength requirements is given below:

The inputs, assumed to be available, are:

- Ship displacement and horsepower
- ASPPR ice class
- Nozzle diameter and section profile
- Upper foundation angle θ°,
- Nozzle location (centre/wing).

The steps for calculating the nozzle strength are as follows:

1. Calculate ice force, using the formula:

   $$F_{ice} = K_1 * K_2 * (\Delta HP)^{\beta}$$

2. Calculate nozzle plating thickness using the formula for ice pressure:

   $$P_{nozzle} = 1.5 * P_{stern}$$

3. Calculate nozzle profile section modulus using simplified (rectangular box) profile.

4. Calculate nozzle strength using the formula:

   $$F_{max} = Z * \sigma_y/R * 1.04\ (.645 - \Theta/213)$$

5. Compare F_{max} with F_{ice}. If $F_{max} < F_{ice}$, increase any of (or combination of):

   - Foundation angle,
   - Plating thickness,
   - Profile thickness,
   - Strength of material.

6. Check shear area in radial and longitudinal directions as per paragraph 10.4.

7. Check other requirements, including:

   Bottom attachment,
   Moment of inertia,
   Number of webs

   Detailed list of the requirements is given in Chapter 10 of Volume 1 of the main report.

8. If optimization of the nozzle structure is contemplated, use the programs developed for detailed evaluation of the stresses in the nozzle ring.

A study of the influence of the structural characteristics of nozzle top and bottom support on the nozzle strength should be undertaken.

A study of varying the section properties around the circumference (especially at the foundation) to match the stress distribution should be carried out.

A study of the influence of pressure area distribution on the magnitude of ice impact forces should be carried out.

Limited scope of measurements on an existing nozzle to gather statistical data on nozzle stresses, and full instrumentation of a newly built nozzle followed by full scale testing in ice is recommended.

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LIST OF SYMBOLS

ℓ	Nozzle Profile Length
α_i	Profile Angle of Attack
α	Hoop Force Coefficient
Δ	Ships Displacement
σ_{ice}	Effective Strength of Ice [Pa]
ρ	Water Mass Density [kg/m^3]
ν	Kinematic Viscosity of Water [m^2/s] or in Structures Poisson's Constant
β	Shear Deformation Factor
βi	Exit Angle
σ_y	Yield Stress in Tension [Pa]
δ	Deformations [m]
δp	Diameter, in Meters, of the Propeller (LRS)
γ	Angular Coordinate Along Nozzle Ring [deg]
Θ	Foundation Angle [deg] = 1/2 Angle Over Which Nozzle is Supported
A_{pl}	Area of Nozzle's Outer/Inner Ring Plating
A_{tot}	Total Wetted Surface Area of the Nozzle [m^2]
APP	Arctic Pilot Project
BM	Bending Moment [Nm]
C	Propeller Tip Clearance
CCG	Canadian Coast Guard
C_D	Drag Coefficient [-]
C_f	Friction Drag Coefficient
C_{DN}	Total Drag Coefficient of Nozzle
C_D	Drag Coefficient
C_L	Lift Coefficient of a Profile
C_T	Thrust Coefficient
CPP	Controllable Pitch Propeller
C_{BM}	Bending Moment Coefficient
C_{TF}	Tangential Force Coefficient
C_{SF}	Shear Force Coefficient
C_Q	Torque Coefficient
DIA	Diameter of Nozzle
D	Nozzle Diameter

LIST OF SYMBOLS (Cont'd)

DHP	Delivered Horsepower
D_N	Nozzle Drag [N]
DWT	Deadweight
E	Modulus of Elasticity [Pa]
FI	First year ice
F.P.	Fixed Pitch Propeller
F_{ice}	Ice Impact Force
f	Profile Camber
F	Shear Factor
FEM	Finite Element Method
HP	Horsepower
I	Moment of Inertia [m]
I.D	Inside Diameter
LNG	Liquefied Natural Gas
LRS	Lloyd's Register of Shipping
M	Moment [Nm]
MES	Mitsui Engineering and Shipbuilding
MY	Multi-year Ice
m	Mass of a Ship [kg]
N_n	Nozzle Numeral
NSMB	Netherlands Ship Model Basin
NACA	National Advisory Committee for Aeronautics
s	Profile Thickness
S.C.E.	Specific Crushing Energy (MPa)
Re	Reynolds Number
R	Nozzle Radius [m]
T	Thrust [N]
SF	Shear Force [N]
t_{pl}	Thickness of Nozzle Plating
TF, N	Tangential (Normal) Force [N]
V_{ship}	Ship's Speed [m/s]
U	Strain Energy in Flexure [T]
x,y,z	Ship Coordinates: x - Longitudinal Axis y - Transverse Axis z - Vertical Axis
Z	Section Modulus [m^3]

1. INTRODUCTION

Nozzles (also known as Kort Nozzles, Shrouds or Ducts) have been well established in the marine field for half a century. In conventional marine applications they are used for:

- Augmenting the thrust near bollard conditions.

- Decreasing the installed horsepower for the required thrust.

- Decreasing propeller diameter and increasing propeller RPM as compared to non-shrouded propeller.

- Stabilizing water inflow into the propeller and thus supressing vibration and cavitation.

- Improving ships' directional stability and decreasing propeller emergence in on a seaway.

- The principal applications of nozzles are on:

- Tugs and pushers,
- Slow and moderate speed ships,
- Self-propelled barges,
- Fast navy ships (decelerating nozzles).

In addition to the advantages listed above nozzles can offer the following benefits for icebreaking ships:

- Limitation of the size of broken pieces interacting with the propellers, thus allowing for a smaller/lighter propulsion installation and for the use of a controllable pitch propeller.

- For shallow draft vessels nozzles limit the amount of air being sucked into the propellers. They also limit the potential of damage to the blades due to sea bottom impact.

Among the disadvantages of nozzles frequently quoted is the nozzle intake clogging with ice. Experience gained on Canmar vessels suggests that a properly designed stern and nozzle intake minimize this problem.

Nozzles on icebreaking ships have gained in popularity in recent years. Among ships with ducted propeller installations, we have:

Canmar Kigoriak,
Robert LeMeur,
Canmar Supplier 1 and 2,
Canmar Supplier 7,
Arctic,
Vertador,
Polar Stern,
Ikaluk,
Miskaroo,
Arctic Nanabush,
Arctic Nanook,
Arctic Nutsupok.

Some of the existing designs of nozzles of ice transiting ships are shown on Figures 3.1 to 3.4.

Nozzles are also being proposed for future designs of large ships, some of which are:

Arctic LNG Carrier (Arctic Pilot Project),
Arctic Oil Tanker (Dome),
Polar VIII Icebreaker (CCG),
X10 Icebreaker (Dome).

In order to materialize the benefits listed above, nozzles themselves must be strong enough to effectively protect the propellers. The strength requirements of nozzles are the subject of this study.

2. PROJECT OBJECTIVES

This project defines and examines in substantial detail the strength requirements and potential of propeller nozzles over a full range of propulsion powers and ice interaction scenarios. It will bring to bear and expand upon experience gained over several specific achievements in designing and building propeller nozzles for operating in ice, and make available the essential analytical elements of a comprehensive design guide.

The overall objective of the project is:

- To facilitate the design and regulation of effective and economical ships capable of operating year-round in the Arctic, with particular reference to the design of propeller nozzles.

The project objective is:

- To define and study in detail the factors affecting icegoing propeller nozzle strength requirements and design criteria, achieving the formulation of a general analytical expression which when calibrated can be used for design and regulatory purposes.

In order to achieve these objectives, the following logic flow was developed:

1. Successful existing nozzle designs will be used as a basis for the strength investigations.
2. This basis will be extrapolated to larger nozzle designs.
3. Analytical methods will be used in order to assess the strength of the existing and future nozzle designs.
4. A ship-ice interaction computerized model will be used to assess the influence of ship related variables (speed, displacement, number of shafts and ice conditions) on the ice impact forces acting on the nozzles.

5. Ice forces acting on nozzles will be determined using the combined information on:

   Existing nozzles,
   Designed large nozzles,
   Ship-ice interaction model.

6. Strength requirements will be evolved based on the assessment of the ice forces and existing nozzle performances. These requirements will be the minimum strength requirements.

7. A research and development program will be executed in future aimed at calibration and verification of the proposed regulations.

3. REVIEW OF THE STATE OF THE ART

A literature search identified 31 papers addressing various aspects of nozzle design. The vast majority of them deal with the hydrodynamic design of the nozzles and shrouded propellers. The rest, (Ref. 11, 12, 13, 18, 30, 31) deal with the structural design aspects of the nozzles and/or operational experience with them. All of the classification societies offer design guidance for steering (rotating) nozzles. Steering nozzle strength is treated analogously to that of moving control devices (rudders, skegs). Only one classification society (LRS) offers an in-detail study (Reference 12) of hydrodynamic loading and its effects on the structure of rotating (or fixed) nozzles.

Often nozzle structural design is left to the shipyard, subject to the approval of a classification society. In some cases, consulting firms specializing in hydrodynamic nozzle design offer the structural design package as well (W. Becker of West Germany).

The shipyards competing for the Arctic Pilot Project LNG Carriers did numerous structural design investigations of a 9.2 m diameter nozzle. Among them:

Kawasaki Heavy Industries

- Model testing of ice-propeller interaction of open and shrouded propellers (proprietary to KHI).
- In depth 3D FEM study of stresses, deformations and vibrations behaviour of large, 9.2 m dia nozzles for class 10 ships (proprietary to APP and KHI).

Mitsui Engineering and Shipbuilding

- Design check of Arctic LNG carrier's nozzle for APP (proprietary to APP & MES).

A German shipyard HDW, commissioned a strength study of the nozzles built for the German research ship Polar Stern in 1982.

The largest nozzles fitted on sea-going ships known to the authors are:

VESSEL NAME	DWT tonnes	POWER SHP	NOZZLE I.D. m	YEAR
MS Thorsaga	280,000	34,200	7.3	1973
Golar Nichu	215,000	30,000	7.9	1974
Golar Kanto	215,000	30,000	7.9	1974
Kirsten Maersk	334,000	36,000	8.8	1975

Experience with the large sea-going nozzles has been, in general, positive. However, some problems with cavitation erosion and vibration of the ducts have occurred. These problems have now been overcome.

The Russians outfitted some small craft with nozzles more than two decades ago. However, the experiments were unsuccessful due to frequent clogging of the nozzles with ice. They offer no guidance on the design of ice-resistant nozzles.

In terms of their geometry, nozzles can be categorized as:

Conventional, and
Custom Designed

It is fair to say that there is no "standard" nozzle design. The most common ones are NSMB #19A and #37; however even these are frequently modified to suit specific design requirements.

Marine consultants and shipyards offer their particular designs for the optimum hydrodynamic efficiency. Nozzles, like propellers, can be wake adapted. In addition, astern performance requirements lead often to changes in the nozzle trailing edge geometry for the intended service.

Recently, a number of patented nozzles have appeared on the market (for example Mitsui and Mitsubishi nozzles). Their main advantage is that they can be retro-fitted to existing ships. Due to their geometrical characteristics (they are placed ahead of the propeller), it is unlikely that they will be fitted on icegoing ships.

As mentioned earlier, only LRS offers some guidance (not requirements) for the structural design of the nozzles. The main points of LRS guidelines are:

- Nozzle strength is defined according to a nozzle numeral, which is:

$Nn = HP \times \delta p/100$

HP = horsepower transmitted through the shaft.
δp = diameter in meters of the propeller.

- Nozzle structure should be composed of:

  Fore and aft webs
  ring webs (minimum two)

- There should be a local increase of scantlings in way of the head box and pintle support.

- Minimum thickness of nozzle's plating should be:

$$t_{pl} = 7 + 0.052\ Nn\ (mm)$$

- Maintaining structural continuity is essential.

A comparison of LRS recommended minimum plating thickness and the actual scantlings of icebreaking ship nozzles is shown below:

t_{actual} [mm]	SHIP	LRS t_{min} [mm]
Canmar Supplier	12.1	12.7
Canmar Kigoriak	52.2	35.0
Robert LeMeur	7.7	25.0
Arctic	47.4	25.0

Steering nozzles are not considered as suitable steering devices for icebreaking ships at this time. The main reasons for this are:

- Lower propulsive efficiency than fixed nozzles (for similar geometries).
- Insufficient strength due to the lack of permanent top and bottom attachment.

For these reasons, steering nozzles are excluded from this study.

A summary of two papers dealing with the structural design of fixed and steering nozzles is given below:

Reference 11: The Structural Design of Fixed and Steerable Propeller Ducts, by R.F. Barton.

This paper details hydrodynamic loads on the fixed and steerable nozzles as a function of power installed, stern and duct configuration and helm angle. The maximum sideways hydrodynamic loading of the fixed nozzle is shown to occur during the early stage of turning of the ship. Formulas for side and vertical loading of the nozzle are given. Formulas for bending moment, shear force calculations are given for different nozzle/support/ rudder configurations.

Reference 30 Structural Design of Ducts and Duct Support, by J.B. Caldwell, et al.

This paper presents a detailed design procedure for fixed nozzle designs. Materials, loadings, static design analysis of duct plating, ring frames, and duct supports are given. A simplified dynamic response of the duct-support configuration is analysed.

The state-of-the-art in structural design of the nozzles is best seen by the examination of actual nozzle structures. Existing nozzle structural properties are shown in Table 3.1.

Structural details of four existing nozzles are shown in Figures 3.1 to 3.4.

Two general observations can be made:

- nozzles are very complex structures,
- no trends or standards in structural design can be detected.

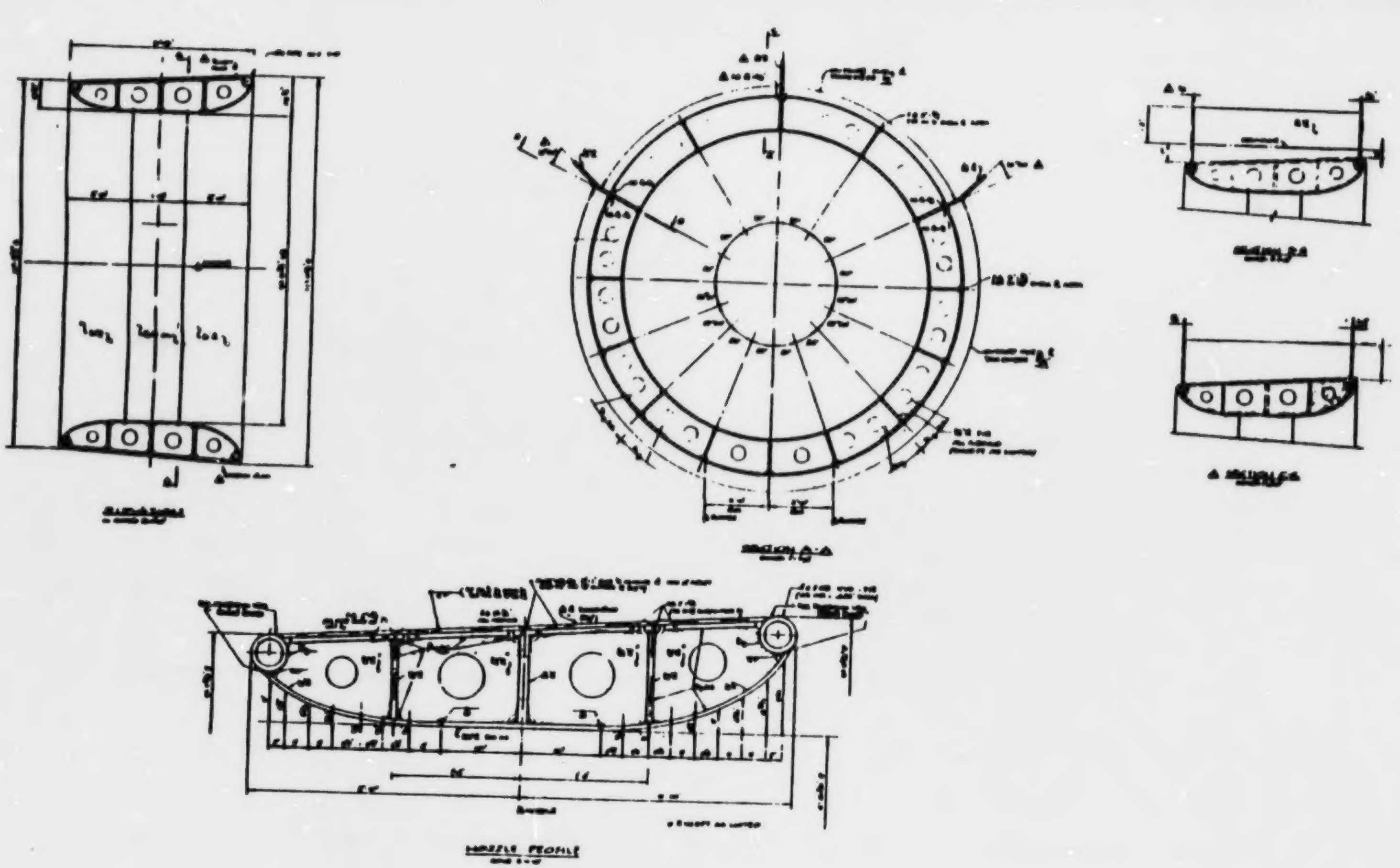
SHIP	VESSEL DISPLACEMENT TONNES	HORSEPOWER/ SHAFT	NOZZLE DIAMETER, m	PLATING THICKNESS, cm	NR OF RING WEBS	SECTION MODULUS, cm^3	CALCULATED* MAXIMUM FORCE, TONNES	ASPPR ICE CLASS
Kigoriak	7000	16400	5.33	3.5	3	49,319	1427	3
Robert LeMeur	5000	4500	3.03	2.5	3	13,125	1000	3
Supplier 1 & 2	2300	3500	2.8	1.27	3	8,757	387	2
Supplier 7	1774	2500	2.6	1.25	4	6,613	189	2
Arctic	36000	14400	5.4	2.5	2	24,712	350	2

* See Chapter 8 for the details of calculations.

TITLE:

NOZZLE PROPERTIES OF EXISTING SHIPS

TABLE 3.1



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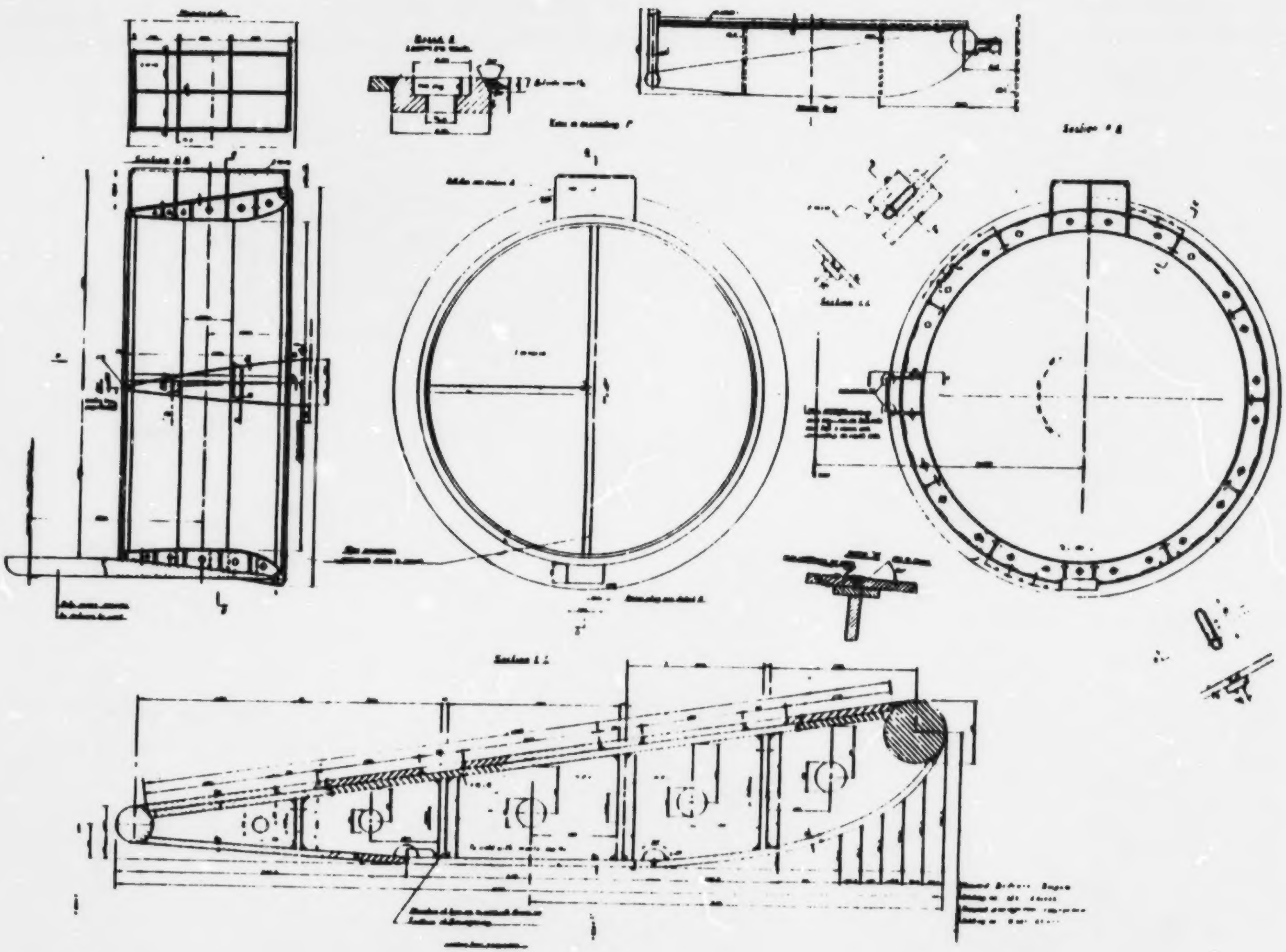
Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Structural Details Of
The Nozzle Of Supplier 1 and 2

FIGURE No. 3.1



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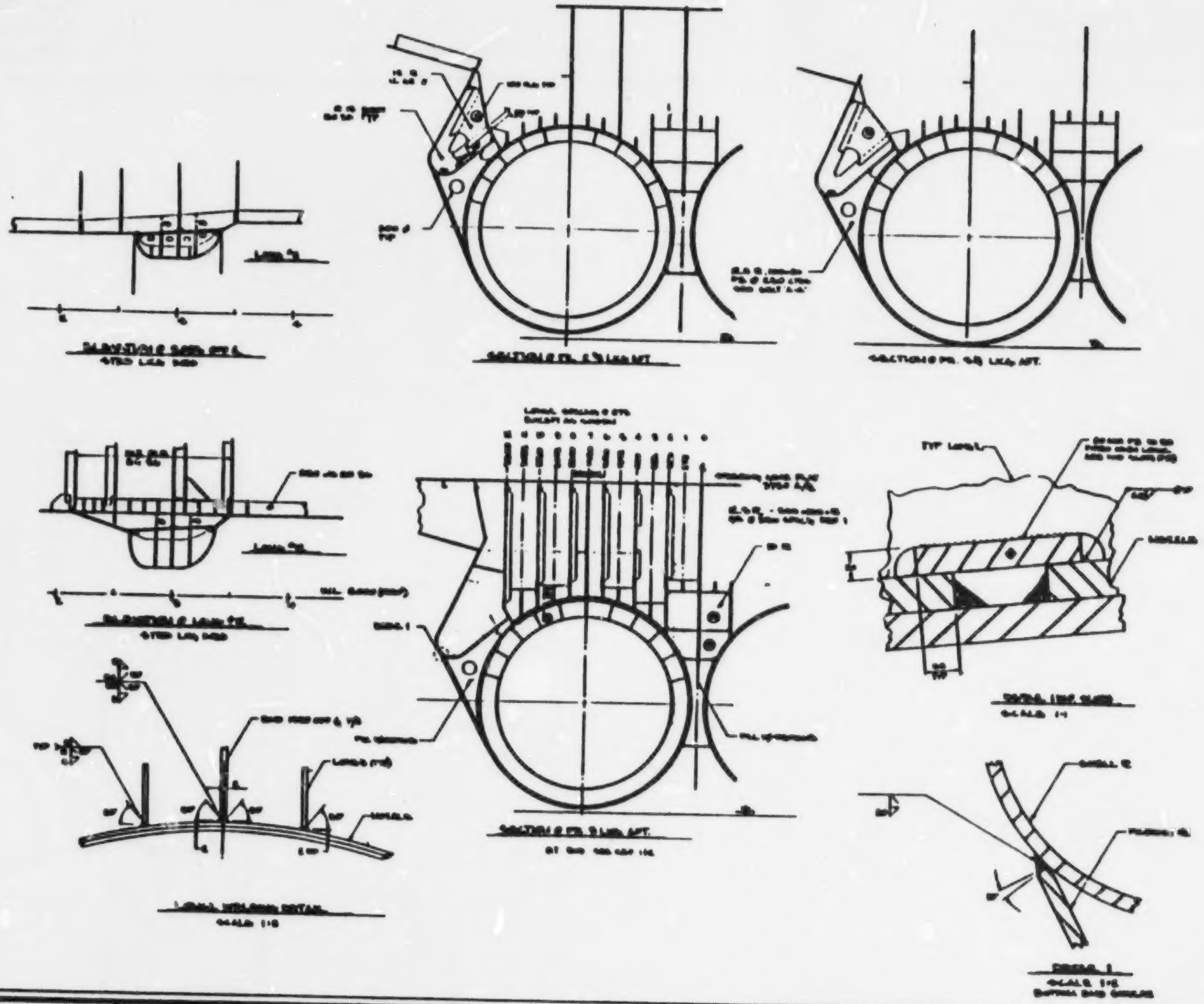
Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Structural Details Of The Nozzle Of A Tug

FIGURE No. 3.2



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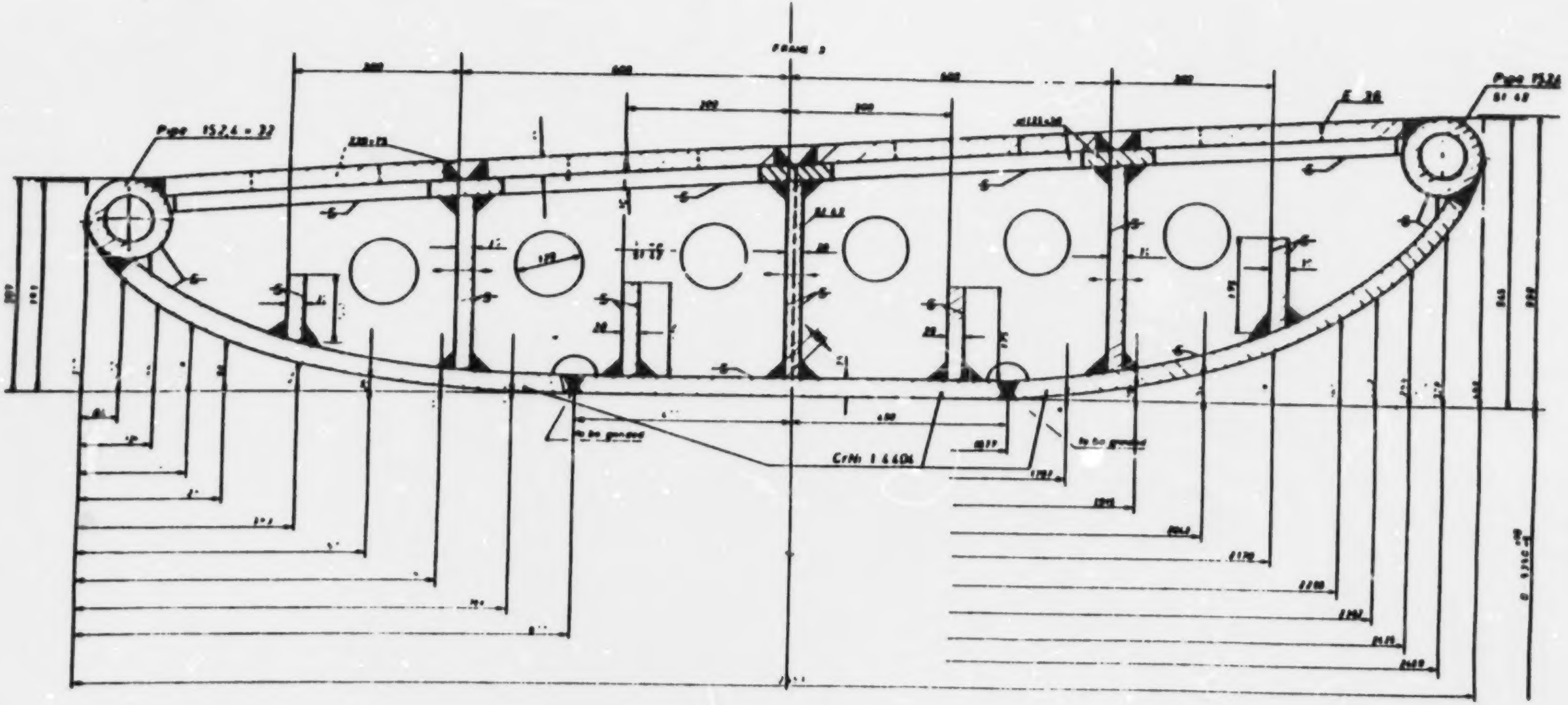
Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Structural Details Of
The Nozzle Of Robert LeMeur

FIGURE No. 3.3


Pipe 152,4 = 22
FRAME 3
E 36
CrNi 1.4406
to be ground
to be ground

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Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Structure Details Of The Nozzle Of MV Kigoriak

FIGURE No. 3.4

4. RANGE OF SHIPS AND POWERS INVOLVED

Table 4.1 summarizes the recent trends in icebreaking ships.

Note that the number of new ships outfitted with nozzles is growing and it constitutes approximately 40% of the total population of ship classes.

Table 4.2 summarizes the icebreakers outfitted with shrouded propellers. Note that due to the small size and power of icebreaking ships, the sizes of ice-going nozzles are lagging behind their open water counterparts.

Table 4.3 shows the projected developments of icegoing ships known to the authors. It is evident that at this time there is a large "jump" in size and power of future ships involved in Arctic transportation.

Consequently, we will attempt to analyze the cases within the present state of the art of nozzle design with the view of extrapolating the size and power further into the future.

The state of the art in nozzle design at this time is for a 9.2 m diameter propeller of 75,000 hp on each of two shafts for a 140,000 m^3 LNG carrier (APP). Complete designs exist for this ship. On the other end of the scale, the smallest nozzle installation for an Arctic Class 2 vessel is 3260 hp/shaft.

Figure 4.1 shows schematically the relationship of power versus propeller disk area for shrouded propellers for some existing and future ships. The following formula gives a good fit:

$$\text{Disk Area} \approx HP^{0.88}/232 \quad (\text{Disk area in } m^2) \text{ or,}$$

$$\text{Disk Area} \approx (kW)^{0.88}/177$$

This formula should not be used as a design tool, as it is a trend indicator only.

In order to cover the full range of possible applications, the following four selections were chosen for study in this report:

1.	50 000 HP	8 m dia propeller
2.	20 000 HP	6 m dia propeller
3.	8 000 HP	4 m dia propeller
4.	2 000 HP	2 m dia propeller

These are representative values derived from Figure 4.1 and rounded off for ease of computation.

In order to estimate the forces acting on the nozzles, displacements of the ships have to be assessed. Using state-of-the-art designs, we arrive at the following approximate values:

DHP	DISPLACEMENT, TONNES
50,000 (x2)	300,000
20,000 (x1)	15,000
8,000 (x2)	10,000
2000 (x2)	2,000

SHIP NAME	YEAR DEL.	ICE CLASS	NR OF SHAFTS /NOZZLE	POWER SHAFT	PROP DIA.	DISPLACE-MENT/DWT
	-	-	-	(SHP)	(M)	(TONNES)
Ikaluk	1983	4	2/Nozzle	7,450	3.75	1898 (DWT)
Miskaroo	1983	4	2/Nozzle	7,450	3.75	1898 (DWT)
Terry Fox	1983	4	2	10,800	4.8	7,069
Kalvik	1983	4	2	10,800	4.8	7,069
Robert LeMeur	1982	3	2/Nozzle	4,500	3.00	5,620
Shirase	1982	-	3	10,000		11,600
Polar Stern	1982	-	2/Nozzle	8,700	3.85	3900 (DWT)
Norilsk	1982	ULA	1	21,000	5.6	20,000 (DWT)
Max Waldeck	1981	-	1	3,000	N/A	1,120
Canmar Kigoriak	1979	3	1/Nozzle	16,400	5.3	7,000
"R" Class	1978-80	3	2	6,800	4.12	7,721
Almirante Irizar	1978	-	2	8,100	N/A	14,800
Arctic	1977	2	1/Nozzle	14,400	5.4	36,000
Polar Sea	1976	6	3	20,000	4.7	13,190
Polar Star	1976	6	3	20,000	4.7	13,190

CANADIAN MARINE DRILLING LIMITED

STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE:
SELECTIVE SUMMARY OF RECENT DEVELOPMENT OF ICEBREAKING SHIPS

TABLE 4.1

SHIP NAME	YEAR	POWER/SHAFT	ICE CLASS
Canmar Suppliers 1 and 2	1971	3520	2
Canmar Supplier 7	1975	2640	2
Arctic	1977	14400	2
Canmar Kigoriak	1979	16400	3
Robert LeMeur	1982	4500	3
Arctic Nanook	1982	3260	2
Arctic Nutsukpok	1982	3260	2
Miskaroo	1983	7450	4
Ikaluk	1983	7450	4
Arctic Nanabush	1984	3600	2

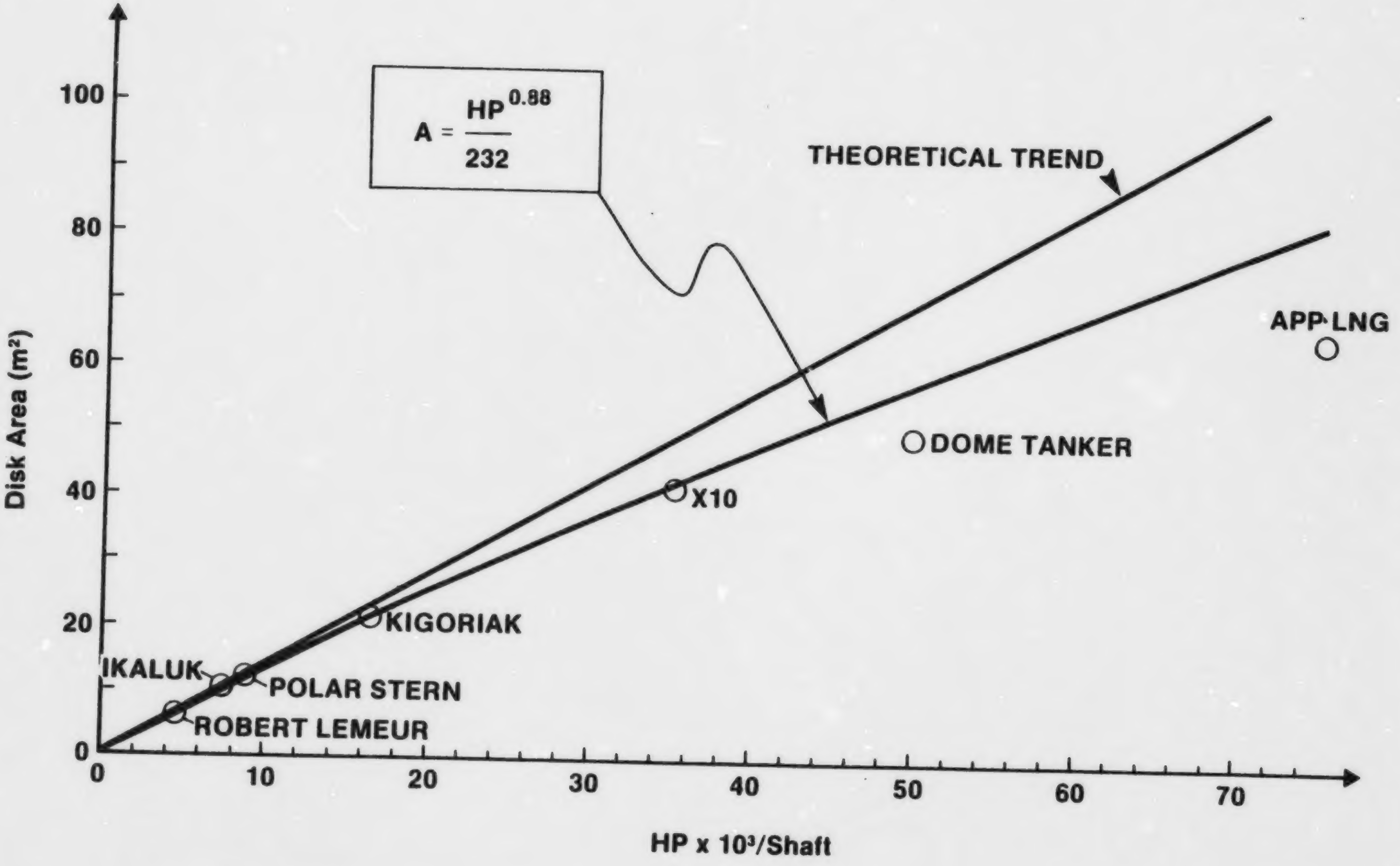
TABLE 4.3

DESIGNED ICEBREAKING SHIPS OUTFITTED WITH THE NOZZLES

SHIP NAME	YEAR	POWER/SHAFT	ICE CLASS
Polar VIII	1983	33000	8
APP LNG Carrier	1982	75000	10
Dome Tanker	1983	50000	10
X10	1983	35000	10

TITLE:
ICEBREAKING SHIPS OUTFITTED
WITH NOZZLES

TABLE 4.2



CANADIAN MARINE DRILLING LIMITED

Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: **Disk Area Versus Horsepower For Shrouded Propellers**

FIGURE No. 4.1

5. BASIC NOZZLE GEOMETRIES, LOCATIONS AND ATTACHMENTS

5.1 Geometries

Nozzles are rings made of airfoil-type sections. The sections are custom-designed or selected from published data (Ref 16).

Table 5.1 summarizes general geometrical properties of NSMB Wageningen tested nozzles, which are the commonly used. Those tested by NSMB in the last 3 decades are largely based on NACA profiles. Details of these profiles are given in Table 5.2.

Each profile, whether custom made or not, is characterized by:

Length	- Distance joining two extremities of the profile.
Camber	- Maximum distance between thickness line and the base line.
Thickness	- Maximum thickness of the profile.
Leading and Trailing Edges	- Curvature defined by the radius of the circle forming fore and aft extremities of the nozzle.

The profiles are set at an angle to the horizontal with the propeller disk placed about mid-way along the length of the nozzle. Figure 5.1 illustrates basic nozzle profile geometry.

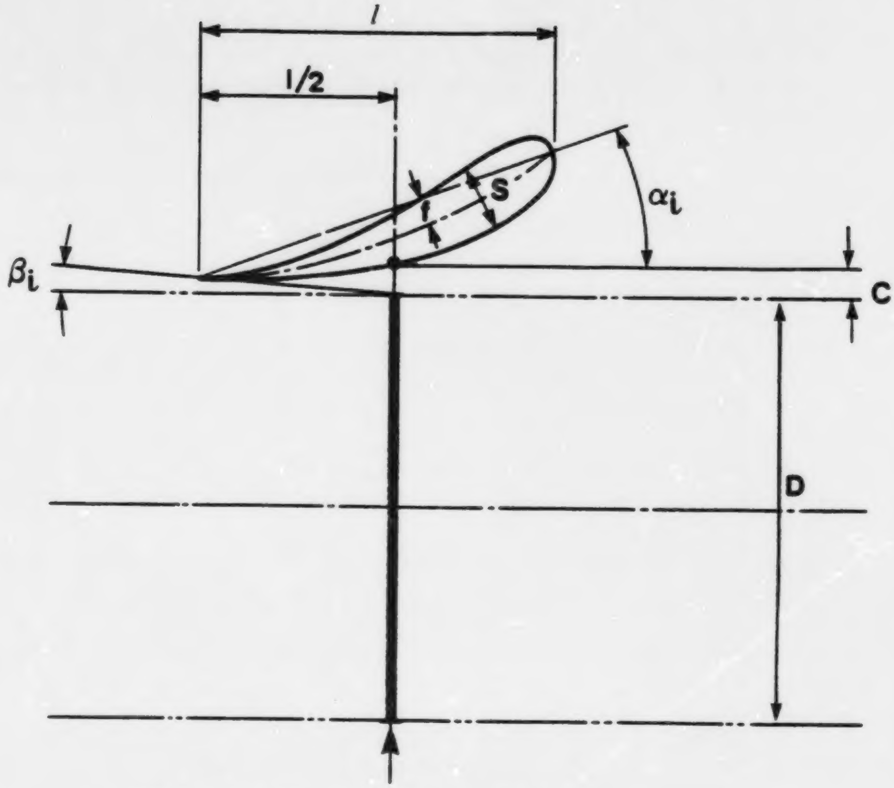
Custom designed nozzles are essentially similar to the NSMB nozzles with the modifications reflecting the particular duties required by the designer. In general, the following rules apply:

- For the highest possible thrust at very low speeds, profiles used have high camber, high angle of entrance and are long.
- For good performance at moderate speeds, profiles have low entrance angles, thin profile and small camber.
- For good performance astern, nozzles should have thick trailing edges and large angle β.

NOZZLE NR	ℓ/D	s/ℓ	f/ℓ	α_i	PROFILE NACA
1				AXIAL CYLINDER	
2	.67	.15	.04	12.7	4415
3	.50	.15	.04	12.7	4415
4	.83	.15	.04	12.7	4415
5	.50	.15	.04	15.2	4415
6	.50	.15	.04	10.2	4415
7	.50	.15	.05	12.7	5415
8	.50	.15	.03	12.7	3415
10	.40	.15	.05	12.7	5415
11	.30	.15	.05	12.7	5415
18	.5	.15	.09	10.2	9415
19	.5	.15	.07	10.2	7415
20	.5	.15	.05	10.2	5415
21	.7	.15	-	-	-
22	.8	.15	-	-	-
23	.9	.15			
24	1.0	.15			
19A	.5	.15			
37	.5	.19			
30	.6	.15)			
31	.6	.15)			
32	.6	.15)			
33	.6	.15)	Decelerating Nozzles		
34	.6	.09)			
35	.9	.1125)			
36	1.2	.0750)			

Note: Values of f/ℓ, α_i and profile for the nozzles 21 to 37 and 19A were not available.

CANADIAN MARINE DRILLING LIMITED	STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS	TITLE: NOZZLE GEOMETRY PARTICULARS TABLE 5.1



PROPELLER DISK PLANE

SYMBOLS:

D	PROPELLER DIAMETER
α_i	ENTRANCE ANGLE
s	MAXIMUM THICKNESS
f	CAMBER
l	LENGTH OF NOZZLE
C	CLEARANCE
β_i	EXIT ANGLE

CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Definition Of Nozzle Geometry FIGURE No. 5.1

Due to the difficulties in manufacturing profiles with two-directional curvatures, many attempts have been made to adopt nozzles with simplified shapes (see Figure 5.2 for some examples). Some of the most popular nozzles (NSMB #19A and #37) have simplified single-curvature outer surface.

Figure 5.3 shows an example of nozzle geometry.

In a summary, nozzle geometries can be expressed as follows:

Nozzle Length/Diameter - $0.5 < \ell/D < 0.8$
Thickness/Length Ratio - $0.07 < s/\ell < 0.19$
Entrance Angle - $10.2 < \alpha_i < 15.2$
Camber - $0.03 < f < 0.07$

For the sake of simplicity, structural configuration of the nozzle can be thought to be that of a thick cylinder having inner diameter D, averaged thickness s_{AV}, and length ℓ. Figure 5.4 shows the graphical representation of the simplified-ring nozzle.

The basic structural elements shown in Figure 5.4, of nozzles are:

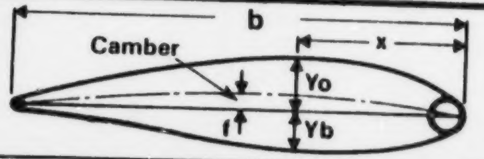
Upper foundation (head box).
Lower foundation (Pintle support).
Outer plating.
Inner plating.
Ring webs (web frames)
Girders.
Leading edge (round pipe/castings).
Inner longitudinals.
Outer longitudinals.
Trailing Edge (round pipe).

Some geometrical and structural characteristics of existing nozzles are shown in Table 5.3. Figure 5.5 shows the trend in section modulus of the existing nozzle rings as a function of nozzle ring diameter.

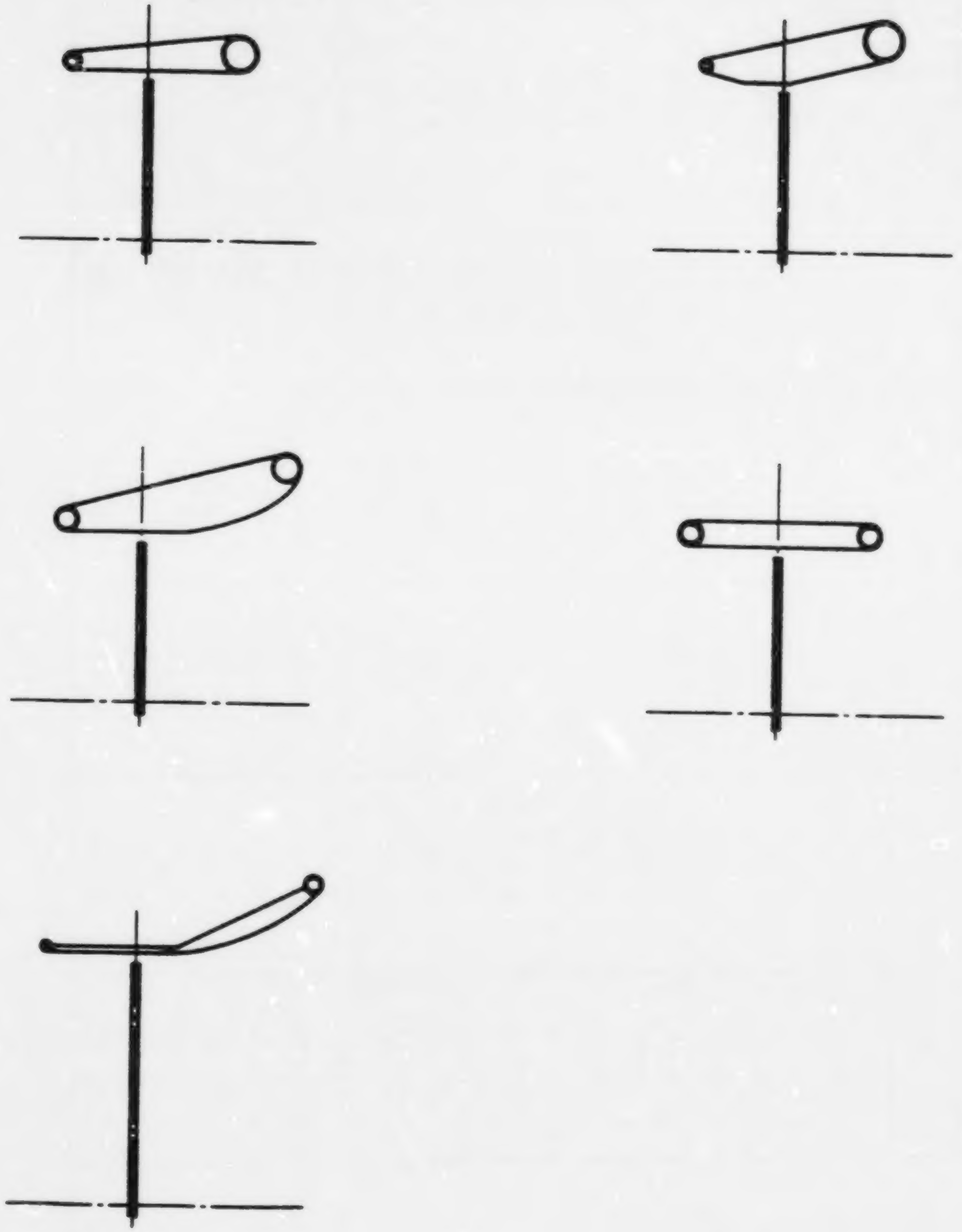
Tip clearance C is customarily held at 0.4% to 1% of nozzle radius. This clearance may be a very important one from the viewpoint of allowable deformations. As increasing tip clearance reduces the efficiency of the nozzle-propeller system, there exists a tendency to minimize this gap.

Abscissa x/ b	Profile					
	NACA 4415		NACA 5415		NACA 3415	
	Yo	Yb	Yo	Yb	Yo	Yb
0	—	0	—	0	—	0
1.25	3.07	- 1.79	3.23	-1.63	3.91	-1.95
2.5	4.17	- 2.46	4.38	-2.27	3.96	-2.71
5.0	5.74	- 3.27	6.05	-2.96	5.43	-3.58
7.5	6.91	- 3.71	7.31	-3.31	6.51	-4.11
10	7.84	- 3.98	8.32	-3.50	7.36	-4.46
15	9.27	- 4.18	9.91	-3.54	8.63	-4.82
20	10.25	- 4.85	11.01	-3.39	9.49	-4.91
25	10.92	- 3.98	11.79	-3.11	10.05	-4.85
30	11.25	- 3.75	12.19	-2.81	10.31	-4.69
40	11.25	- 3.25	12.25	-2.25	10.25	-4.25
50	10.53	- 2.72	11.51	-1.74	9.55	-3.70
60	9.30	- 2.14	10.20	-1.24	8.41	-3.03
70	7.63	- 1.55	8.39	-0.79	6.87	-2.31
80	5.55	- 1.03	6.12	-0.46	4.99	-1.59
90	3.08	- 0.57	3.39	-0.26	2.77	-0.88
95	1.67	- 0.36	1.83	-0.20	1.51	-0.52
100	0.16	- 0.16	0.16	0.16	0.16	0.16

Symbols:



CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Ordinates of Nozzle Profiles Based on Percent of Length
		TABLE No. 5.2



CANADIAN
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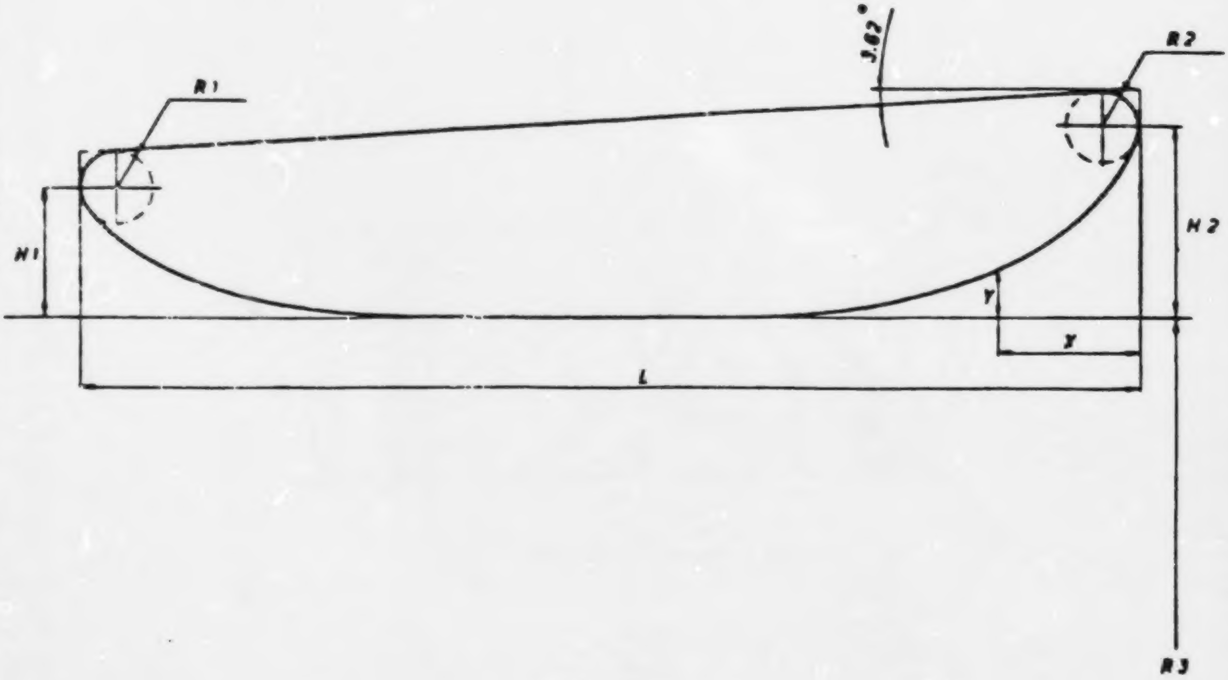
Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Nozzles With Simplified Forms

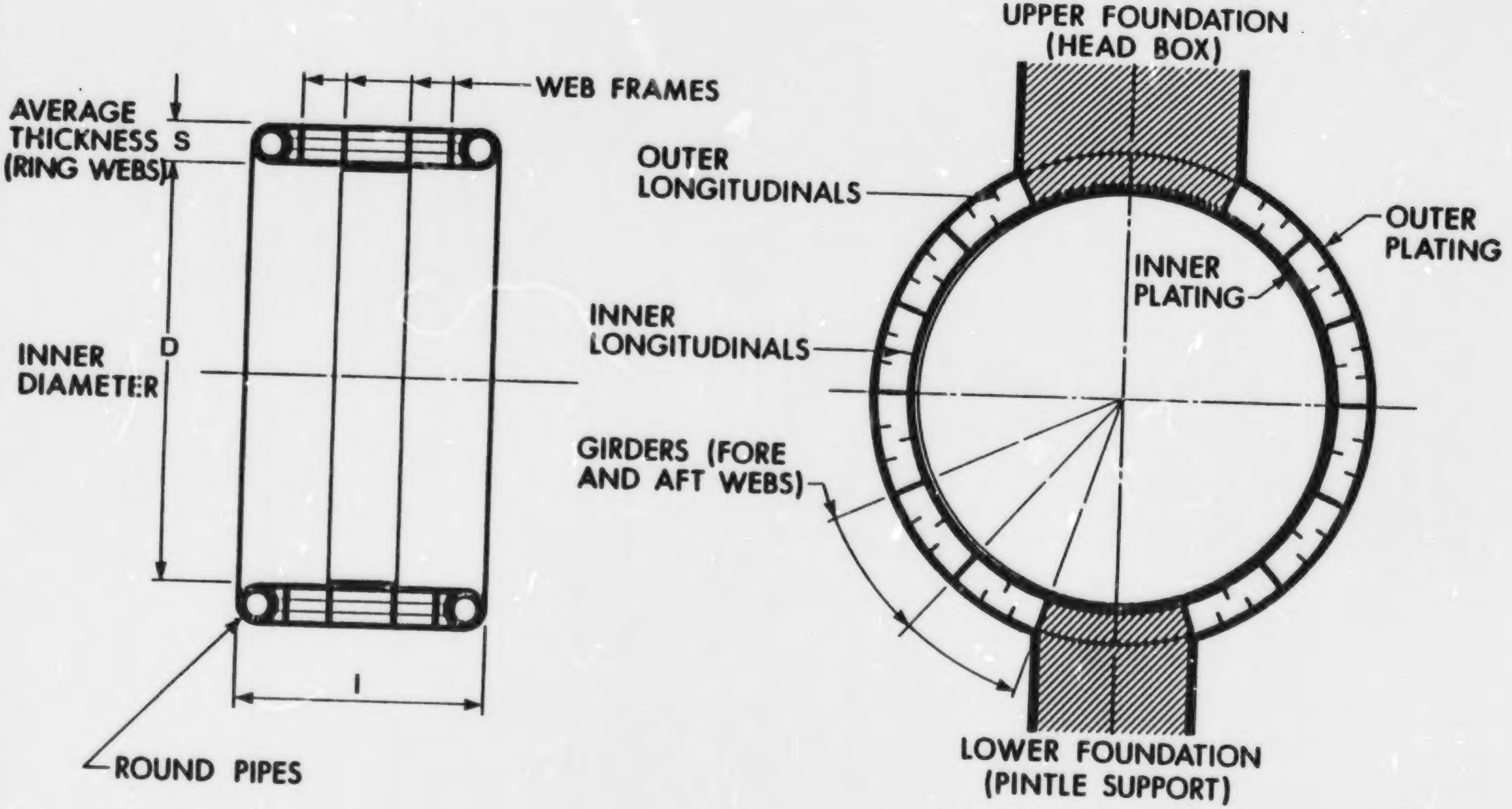
FIGURE No. 5.2

DIMENSIONS IN % OF NOZZLE LENGTH	
X	Y
1.30	14.75
3.91	11.15
7.82	7.66
15.63	3.60
26.05	0.83
36.47	0.05
	STRAIGHT
68.74	0.05
79.16	0.88
89.58	3.85
94.79	6.30
97.39	8.23

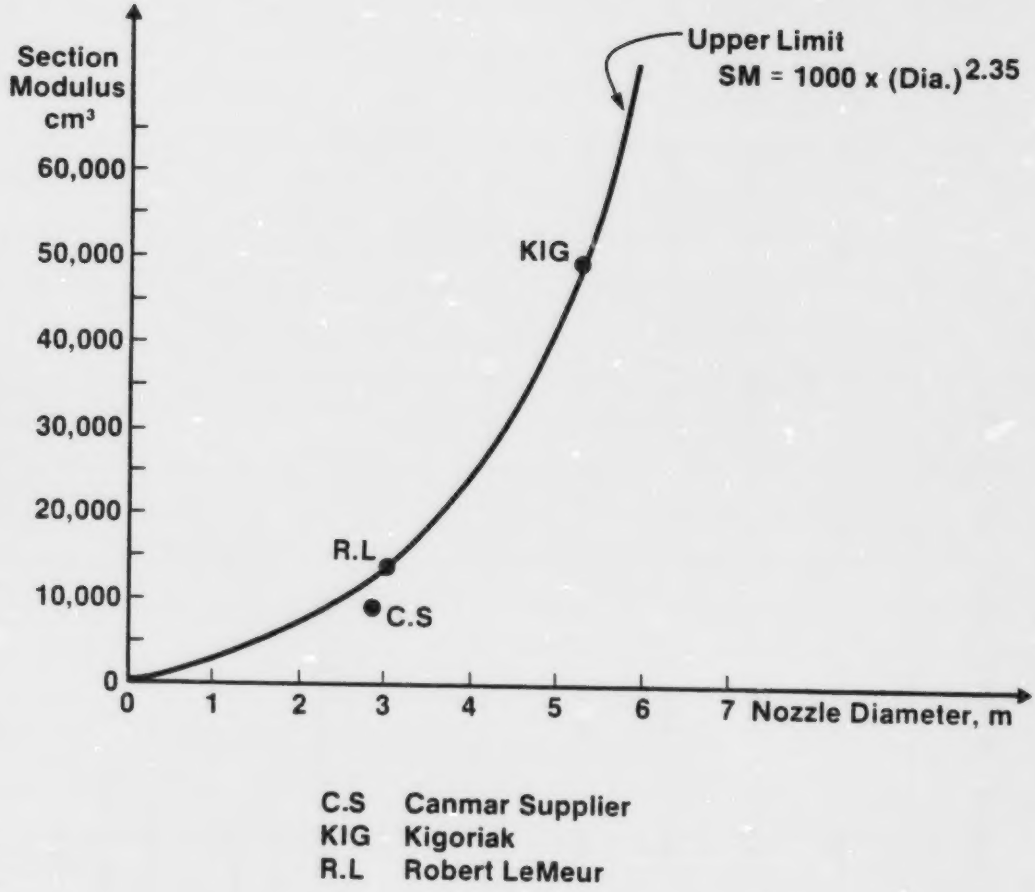


TITLE: Typical Nozzle Geometry

FIGURE No. 5.3


WEB FRAMES
AVERAGE THICKNESS S (RING WEBS)
INNER DIAMETER
D
l
ROUND PIPES
UPPER FOUNDATION (HEAD BOX)
OUTER LONGITUDINALS
OUTER PLATING
INNER PLATING
INNER LONGITUDINALS
GIRDERS (FORE AND AFT WEBS)
LOWER FOUNDATION (PINTLE SUPPORT)

CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Schematic Structural Configuration Of The Nozzle FIGURE No. 5.4



CANADIAN
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Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Section Modulus As A Function Of Nozzle Diameter For Existing Ships

FIGURE No. 5-5

SHIP'S NAME	DISPLACEMENT	HP/SHAFT	NOZZLE DIAMETER	$\ell \times s$[1]	Z[2]	A_{tot}[3]	A_s[4]	t_{pl}[5]	t_{web}[6]	WEBS	θ°[7]
Canmar Supplier	2300	3500	2.8	1.72 x .32	8757	747	308	1.27	1.9	5	65°
Canmar Kigoriak	7000	16400	5.3	2.68 x .46	49320	2681	805	3.5	3.5	5	45°
Robert LeMeur	5000	4500	3.0	1.5 x .3	13125	1125	375	2.5	2.5	5	90°
Arctic	36000	14400	5.4	2.59 x .35	24713	1645	350	2.5	2.5	4	8.5°

NOTES:

1. Section profile length x thickness [m x m].
2. Section modulus [cm^3].
3. Total section area [cm^2].
4. Shear area [cm^2].
5. Plating thickness [cm].
6. Web plating thickness [cm].
7. Half foundation angle.

CANADIAN
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STRENGTH REQUIREMENTS FOR
NOZZLES FOR ICE
TRANSITING SHIPS

TITLE:
STRUCTURAL CHARACTERISTICS OF EXISTING NOZZLES OF ICE TRANSITING SHIPS

TABLE 5.3

5.2 Nozzle Locations

There are two basic locations for the nozzles: Centre, (single or multiple) and wing. Figure 5.6 shows the locations schematically. Examples of centrally located nozzles are:

Canmar Kigoriak,
Robert LeMeur,
Arctic.

An example of a wing located nozzle is:

Polar Stern.

Location of the nozzle can be linked to the concept of protection of the nozzle by the hull. Intuitively, one can anticipate that a centrally located nozzle is better protected against ice pieces approaching from the side. This concept will be discussed in detail in the chapter dealing with interaction scenarios.

5.3 Nozzle Attachments

Attachment of the nozzle to the hull depends largely on the nozzle location.

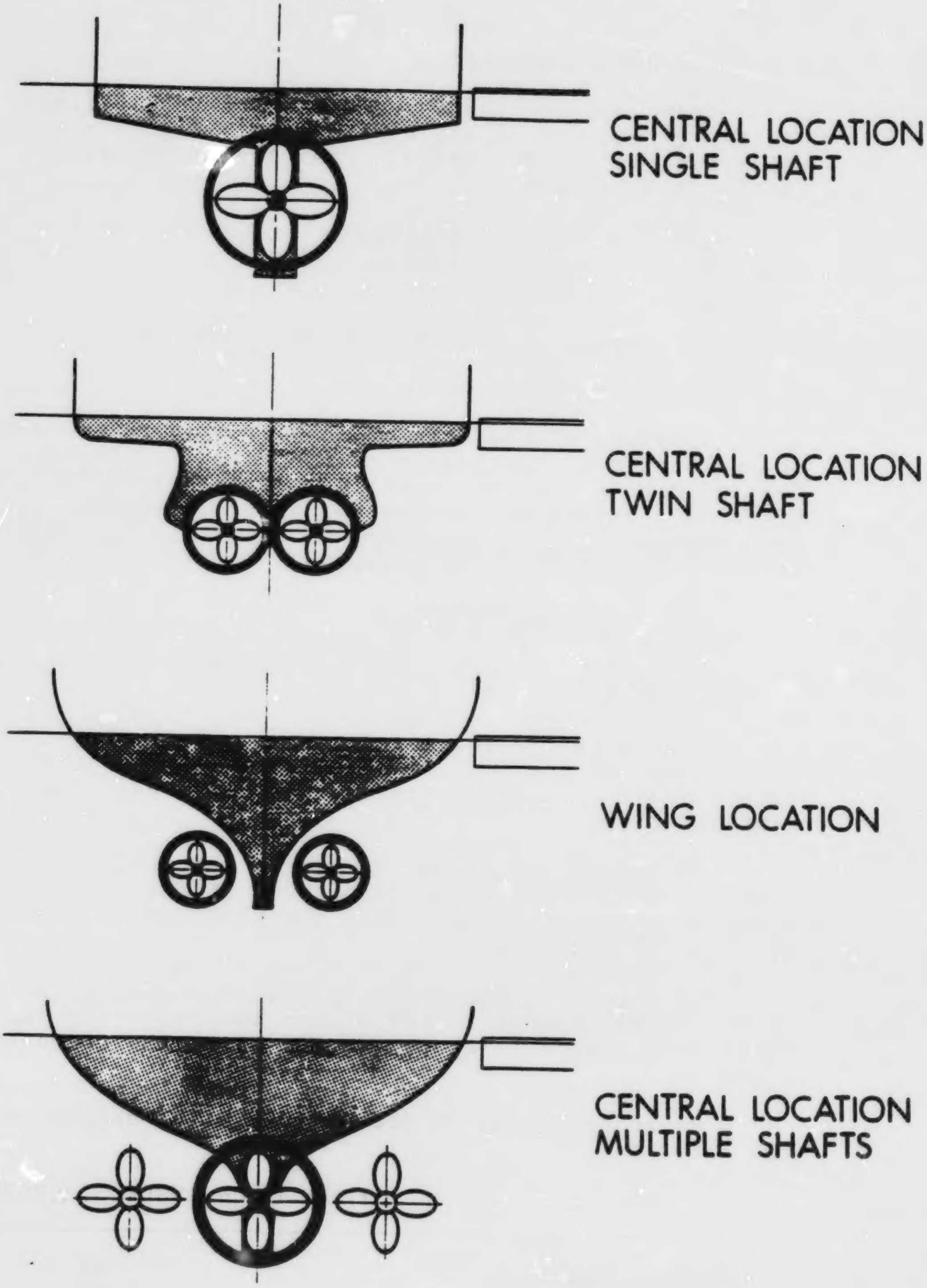
Centrally located nozzles have usually upper and lower parts of the ring fixed to the hull and stern frame, respectively. Figure 5.7 shows the different support configurations.

In general it is well accepted that the nozzle support reduces the effective thrust of the nozzle by creating a "dead" angle. Thus the tendency is to minimize the size of the support.

As a rule of thumb for open water designs the width of the upper support is 1/5 of the length of the duct, which corresponds to approximately 6° of the foundation angle Θ.

Foundation angle Θ for some existing ships are tabulated below:

SHIP	FOUNDATION ANGLE Θ, DEGREES
Canmar Kigoriak	45
Robert LeMeur	90
Supplier 1 & 2	64
Supplier 7	36
Arctic	8.5

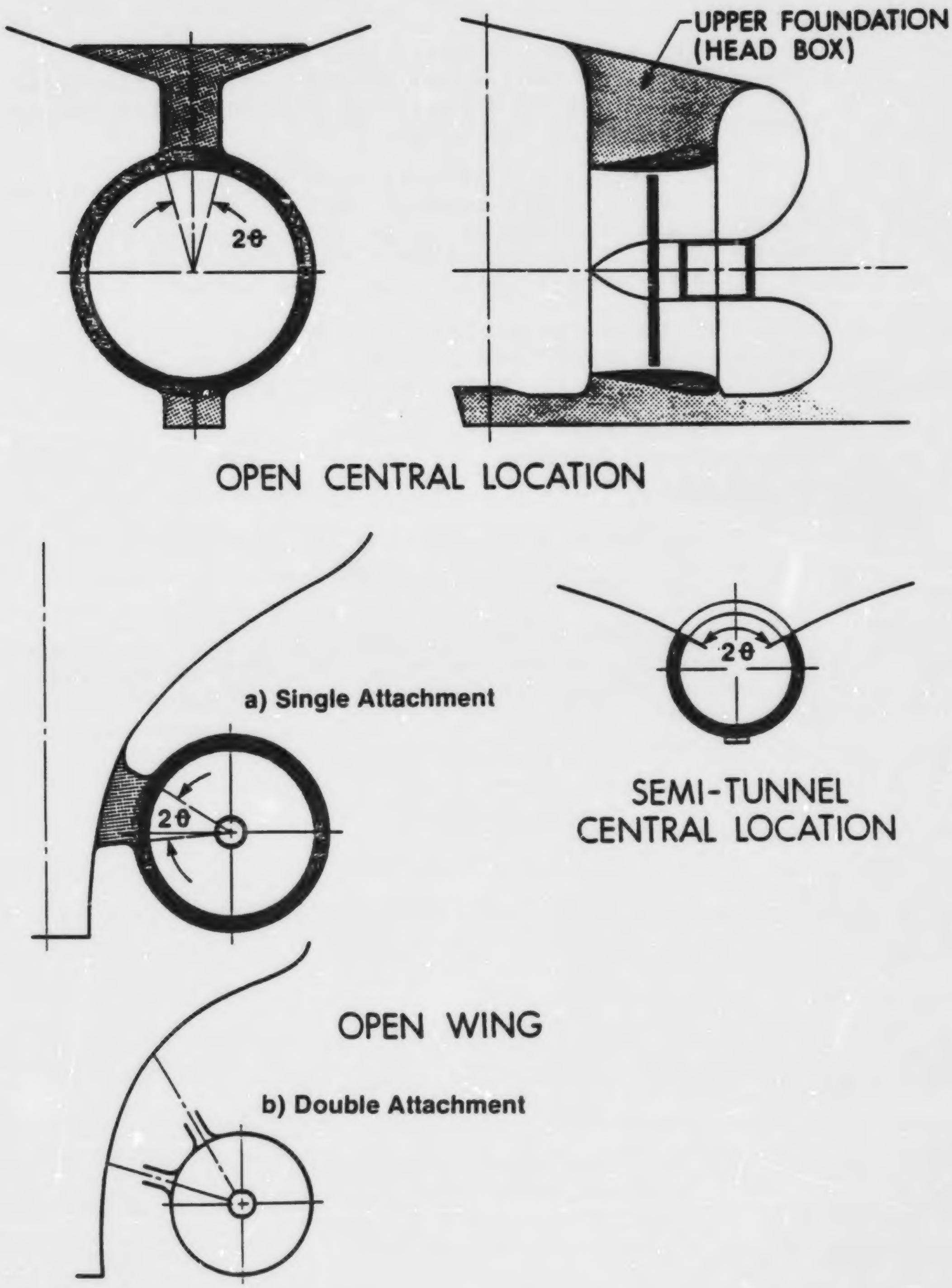

CENTRAL LOCATION
SINGLE SHAFT
CENTRAL LOCATION
TWIN SHAFT
WING LOCATION
CENTRAL LOCATION
MULTIPLE SHAFTS

CANADIAN MARINE DRILLING LIMITED

Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: **Nozzle Locations**

FIGURE No. 5.6


UPPER FOUNDATION
(HEAD BOX)
2θ
OPEN CENTRAL LOCATION
a) Single Attachment
2θ
2θ
SEMI-TUNNEL
CENTRAL LOCATION
OPEN WING
b) Double Attachment

CANADIAN MARINE DRILLING LIMITED	**Strength Requirements For Nozzles For Ice Transiting Ships**	**TITLE: Nozzle Attachement To The Hull** **FIGURE No. 5.7**

For the shallow draft vessels, however, semi-tunnelled nozzles are popular as they make possible the installation of a propeller having a diameter larger then the draft of the ship.

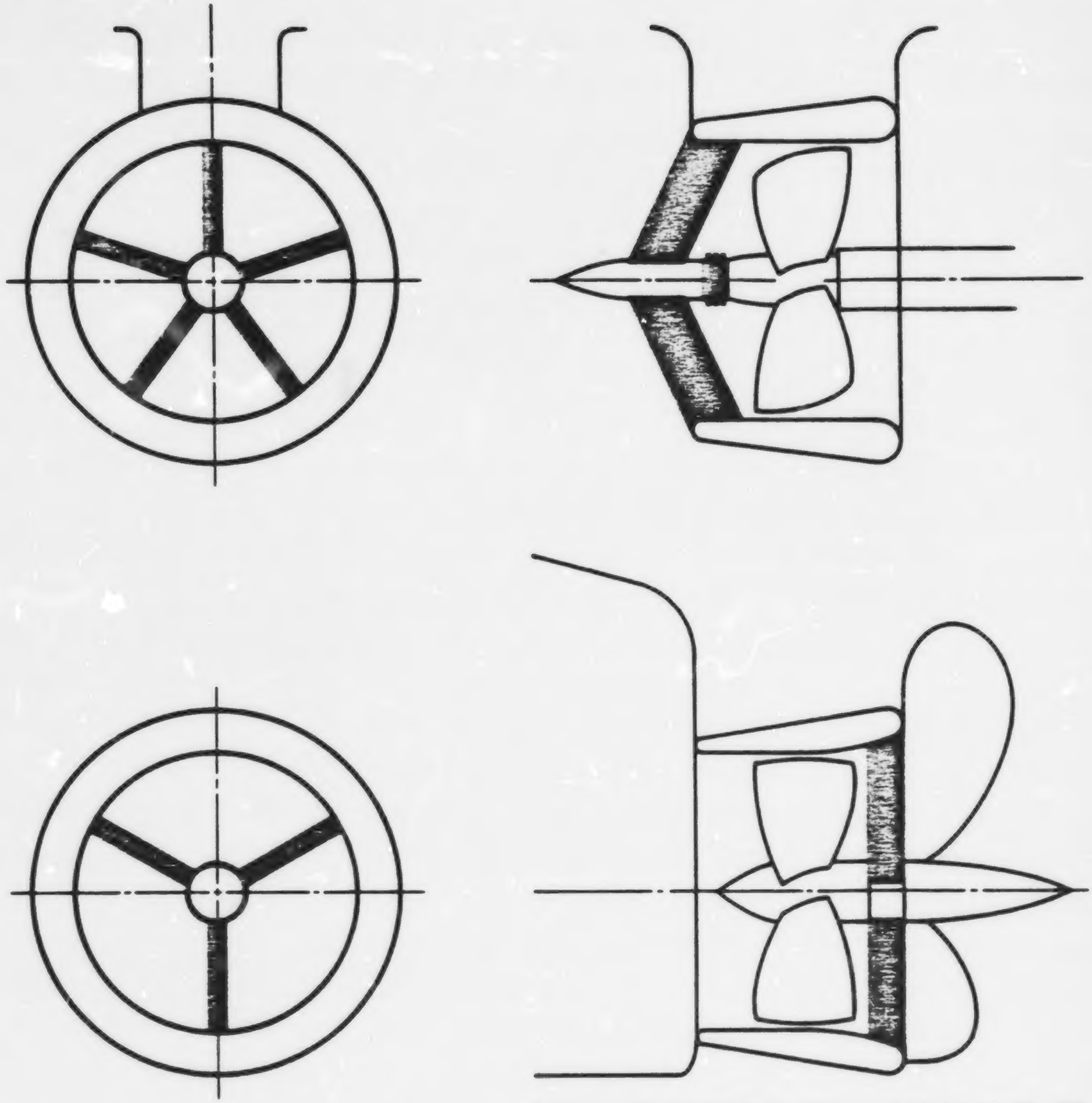
Structural effectiveness of the bottom attachment is questionable. Stern frame's sole pieces are conventionally designed to provide support for the rudder only. Thus it is conceivable that the sole piece provides in certain cases a load rather than support for the nozzle.

Wing located nozzles have customarily single or double attachment (see Figure 5.7). Some wing nozzles however are connected to the shaft support brackets.

In addition to the top and bottom attachment, some nozzles are reinforced by one or several struts (fins). Struts can provide several benefits, among them:

- increase of propulsive efficiency,
- nozzle/shaft reinforcement,
- ice inflow limitation.

Struts can be fitted ahead or aft of the propeller disk. Their number is usually 3 or 5 (non-compatible with the number of blades). Figure 5.8 shows some nozzle/strut arrangements.



CANADIAN
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Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Nozzle/Struts
Arrangements

FIGURE No. 5.8

6. RANGE OF ICE FEATURES

Based on Canmar's operating experience in the Beaufort, the following table has been compiled:

ICE FEATURES POTENTIALLY INTERACTING WITH NOZZLES

	SHIP ICE CLASS (ASPPR)				
ICE FEATURE	2	4	6	8	10
Iceberg	No	No	No	No	No
Bergy Bits/Growlers	Yes	Yes	Yes	Yes	Yes
MY Ridges	No	Yes	Yes	Yes	Yes
FY Ridges	Yes	Yes	Yes	Yes	Yes
Level Ice	Yes	Yes	Yes	Yes	Yes

Below a brief justification of the selected features is given.

Icebergs

Whether a ship collides with an iceberg or not is dictated by the operators rather then the ice class of the vessel. Although head on collision is conceivable, and the statistics of such collisions exist, it is most unlikely that the ship would hit sideways one iceberg while avoiding another. Even then, if such a possibility is conceived, it is believed that no special nozzle design features should be accommodated on this account.

Bergy Bits/Growlers

It is probable that the ships operating in the eastern Arctic will frequently collide with the bergy bits or growlers. These frontal collisions will submerge and push down/aside ice pieces. Depending on the hull form, ship's speed and ice features, such a piece may reach the aft end of the ship through sliding along the bottom or side shell. Thus nozzles, especially wing ones, may interact with these ice features.

MY Ridges

Consolidated multi-year ridges imbedded in first year (FY) or multi-year (MY) floes are frequent in the high Arctic. Ships engaged in defending drillships must break them up. Canmar's experience with Kigoriak shows that MY ridges are dealt with frequently. The higher the ice class, the more frequent interactions will be in this type of operation. Class 2, on the other hand, may encounter MY consolidated ridges sporadically and breaking them is not their line of duty. Consequently it is unlikely that the nozzles of Class 2 ships will interact with MY Ridges.

FY Ridges

These are the most common ice features anywhere where level ice is present. All icebreaking ships must deal with them in a transit or ice defence mode. Undoubtedly in a heavy FY ridge field transit there exists a high likelihood of frequent nozzle-ice interaction.

Level Ice

It is obvious that the ship's nozzle(s) will possibly interact with fragmented level ice pieces sometimes. Severity of this interaction may depend on the hull form and other detail design features.

It is evident that level ice should be excluded from further considerations, since, wherever it occurs, ridges are present which will lead to higher loads.

Regarding size, ice features can be characterized as follows:

Ice Feature	Mass	Mobility*	Effective Mass
Iceberg	very large	small	infinite
Bergy Bit/Growlers	large	small	finite
MY Ridges	medium	small	infinite
FY Ridges	small	medium	finite
Level ice	small	large	small

*Defined as the ability to move away under impact.

The ice can interact with the nozzle as follows:

Bergy Bit/Growlers	Side/Bottom
MY Ridges	Side/Bottom
FY Ridges	Side/Bottom

In all cases, it is easy to see that ice can be fully confined either by the surrounding ice or by the sea bottom.

For the purpose of ice-nozzle interaction simulation, the concept of the specific crushing energy (S.C.E.) will be used, which denotes the energy needed to crush a unit volume of ice. Thus, ice properties are given as follows:

Ice	S.C.E., MPa
Bergy Bit/Growler	5
MY Ridges	5
FY Ridges	2
Level ice	2

These S.C.E. values will be used to estimate the global forces acting on the nozzle during ice-nozzle interaction. The actual value of specific crushing energy depends on:

- Type of ice;
- Crystallography;
- Strain rate;
- Ship/ice collision geometry, etc.

No reliable model exists at this time to accurately predict ice/ship structure interaction pressures. The value of 5 MPa was chosen to reflect the uppermost band of average pressure at approximately $6m^2$ contact. For smaller areas, higher pressures will result.

All scenarios consider the ice as passive and the ship as active. This stipulates that the severity of interaction is governed by the amount of energy the ship may be dissipating during the interaction, and that the kinetic energy of the ship decides on the maximum value of impact force.

7. INTERACTION SCENARIOS

7.1 Establishing Scenarios

Throughout an icebreaker's life, ice can impact the nozzle from every direction. For the sake of the analysis, however, one needs to select the "worst case" scenarios having clearly defined the direction and magnitude of the ice force.

In order to obtain an insight into the nature of the interaction, we proceeded as set out below:

External impacts are due to global ship-ice interactions. Ice conditions, the ship's operational profile and location of the nozzles may influence the type and severity of the interaction. Three basic scenarios have been identified on Figure 7.1, which are described as follows:

The maximum vertical force can occur when a large block of ice is pushing the nozzle upwards. This has been called grounding on ice.

The maximum transverse horizontal force can occur when the ship is swaying into some immobile ice feature (multi-year ridge, growler, etc.). This has been called swaying into the ice.

The maximum longitudinal force may occur when the ship is ramming ahead (astern) and a nozzle is pushed into solid ice. This has been called ramming the ice. In this case there may be an external and internal ice force.

In order to establish the relative importance of basic parameters of the interactions, a simplified dimensional analysis was performed as follows:

Ship Characteristics

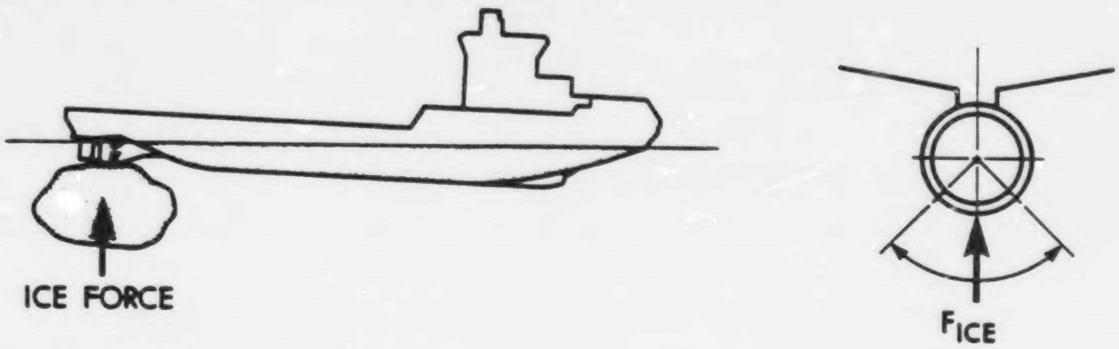
- Mass (displacement)
- Installed horsepower

Ice Characteristics

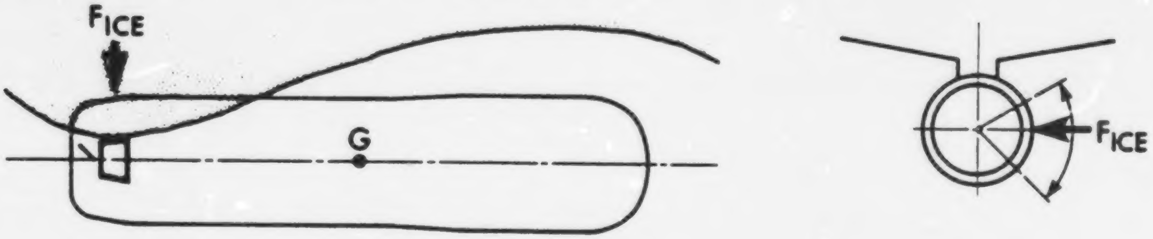
- Effective Pressure/Specific Crushing Energy

Equation used for the dimensional analysis is:

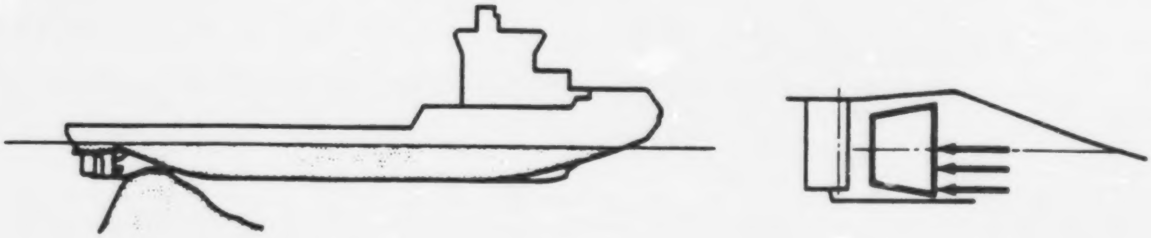
SCENARIO 1 - GROUNDING-ON-ICE



SCENARIO 2 - SWAYING-INTO-ICE



SCENARIO 3 - RAMMING-INTO-ICE



CANADIAN MARINE DRILLING LIMITED	STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS	TITLE: **Basic Interaction Scenarios** FIGURE No. 7.1

Ice Force is proportional to: the $(\text{Mass})^{\alpha}$ * $(\text{Horsepower})^{\beta}$ * $(\text{Ice Strength})^{\xi}$.

This can be translated into a dimensional equation as follows:

$$M^1 L^1 T^{-2} \cong M^{\alpha} * M^{\beta} L^{2\beta} T^{-3\beta} * M^{\xi} L^{-\xi} T^{-2\xi}$$

Where: M - is a dimension of mass (kg),
L - is a dimension of length (m),
T - is a dimension of time (s),

Resulting equations are:

$$\alpha + \beta + \xi = 1$$
$$2\beta - \xi = 1$$
$$3\beta + 2\xi = 2$$

From which the calculated values of exponents α, β, ξ are:

$$\alpha = 2/7$$
$$\beta = 4/7$$
$$\xi = 1/7$$

Thus the relationship has the form:

Force varies as $(m^2 HP^4 \sigma_{ice})^{1/7}$

The parameters, in order of their importance, are:

1. horsepower
2. mass
3. specific crushing energy (ice strength)

It should be made clear that this formulation is one of the many possible expressions and is not to be used for the force prediction purposes.

There are many "hidden" variables not appearing in this formulation. Among them:

- What is the effective pressure of ice σ_{ice}? How does the velocity of impact and mass of the ship influence σ_{ice}?

- What is the contribution of the shape of the impacting body to the magnitude of the ice force?

- Power appears in the exponent $HP^{4/7}$. Doubling the power implies 48% growth of the impact force. But we know that the operator of a high powered ship may be more careful than the same person operating a low powered ship. How do we account for operator's prudence in this formulation?

- What is the influence of nozzle location on the magnitude of ice force?

At this moment, none of the questions listed above can be answered confidently. However, some more insight can be gained through computer simulation of nozzle-ice interaction. For that purpose, the "ICESIM" program was used. Details of the program are described in Appendix C.

7.2 Interaction Simulations

The main objective of the computer runs was to assess the relative importance of ice-nozzle interaction parameters, such as:

- speed of impact,
- geometry of the ice feature,
- size of the ship,
- size and location of the nozzle,
- strength of ice.

It should be made perfectly clear that the absolute values of the interaction forces, accelerations, etc. are not to be used. It is quite conceivable that the error of force estimate may be large when compared with the actually measured forces. Such discrepancies between simulations and reality have been noticed in the past. This is due to the many simplifying assumptions built into ICESIM regarding:

- ice properties;
- ship behaviour; and
- interaction mechanics.

Fourteen runs were executed, covering all of the parameters under investigation. A brief description of these parameters is given below.

Ships

Three (3) different ship types were selected and sketch-designed:

- A 30,000 tonne displacement, 50,000 HP icebreaker in single and twin screw configurations. This ship represents ASPPR ice class 10. The nozzle diameter is 6 m for twin screw and 8 m for single screw.

- 300,000 tonne displacement 2 x 50,000 HP icebreaking tanker with two 8 m diameter nozzles.

Simplified geometries of these ships are shown on Figure 7.2. The ship proportions chosen were based on present design practice. Nozzles are represented as cylinders, with conical intakes.

Ice

The ice was considered to be an immovable, perfectly plastic material, having a specific crushing energy σ_{ice}. No other modes of failure than crushing failure are considered. The friction between ice and ship was set to zero. The strength of ice was set at 5 MPa, representing MY ice.

Ship-Ice Scenarios

Three scenarios were considered:

- head-on impact (ramming),
- side swaying,
- bottom impact.

The geometry of the ice blocks and their locations are shown in Figure 7.2 and it reflects the worst conceivable cases rather then the most probable ones. A permutation of ice-wall inclination angle through 90° - 60° - 30° to horizontal was also performed.

Speeds

The selected ship speeds were 5, 10 and 15 knots for head-on rammings, two and a half knots for bottom impact and two knots for the side impacts.

A summary of the runs is given in Table 7.1. It should be noted that for the head-on rams the force values listed are suspect due to the peculiarities of the nozzle-ice interaction geometries. Specifically the programme calculates the force based on the expression: crushing strength times contact area rather than on the mechanics of penetration. Thus for the large contact areas very large forces can be developed even with no penetration at all.

Description Of Computer Runs

30,000t Displ't 50,000 HP Icebreaker, Single Nozzle:

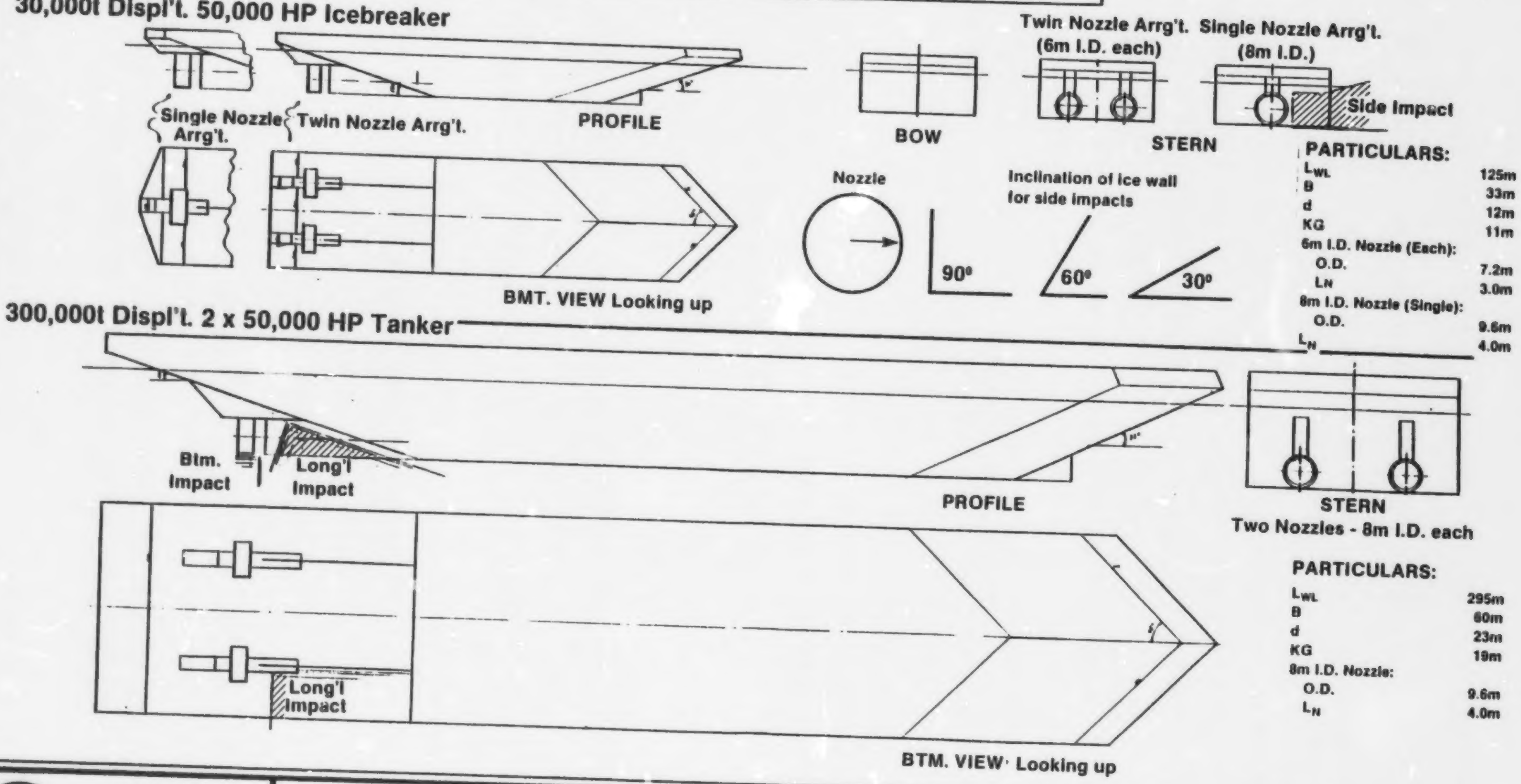
1. Long'l Impact, 15 knots, δc = x MPa
2. Bottom Impact, 2.5 knots, δc = x MPa

30,000t Displ't 50,000 HP Icebreaker, Twin Nozzles:

3. Long'l Impact, 15 knots, δc = x MPa
4. Long'l Impact, 10 knots, δc = x MPa
5. Long'l Impact, 5 knots, δc = x MPa
6. Side Impact, 2 knots δc = x MPa
7. Same as "6" but ice wall-30° Slope
8. Same as "6" but ice wall-60° Slope
9. Btm. Impact, 2.5 knots, δc = x MPa

300,000t Displ't, 2 x 50,000 HP tanker:

10. Long'l Impact, 15 knots, δc = x MPa
11. Side Impact, 2 knots, δc = x MPa
12. Side Impact, 2 knots, δc = 2 x MPa
13. Btm Impact, 2.5 knots, δc = x MPa


30,000t Displ't. 50,000 HP Icebreaker
Single Nozzle Arrg't.
Twin Nozzle Arrg't.
PROFILE
BMT. VIEW Looking up
BOW
Twin Nozzle Arrg't. (6m I.D. each)
Single Nozzle Arrg't. (8m I.D.)
Side Impact
STERN
Nozzle
Inclination of ice wall for side impacts
90°
60°
30°
300,000t Displ't. 2 x 50,000 HP Tanker
Btm. Impact
Long'l Impact
PROFILE
STERN
Two Nozzles - 8m I.D. each
Long'l Impact
BTM. VIEW Looking up

PARTICULARS:

L_{WL}	125m
B	33m
d	12m
KG	11m
6m I.D. Nozzle (Each):	
O.D.	7.2m
L_N	3.0m
8m I.D. Nozzle (Single):	
O.D.	9.6m
L_N	4.0m

PARTICULARS:

L_{WL}	295m
B	60m
d	23m
KG	19m
8m I.D. Nozzle:	
O.D.	9.6m
L_N	4.0m

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Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Input Into Nozzle-Ice Interaction Program

FIGURE No. 7.2

RUN NO.	DISPL, t	NOZZLES	NOZZLE DIA.	SPEED AT NOZZLE kn			ICE ANGLE	STRENGTH	MAXIMUM FORCE DEVELOPED, MN			
			m	X	Y	Z	deg.	MPA	X	Y	Z	TOTAL
1	30,000	1	8	15	0	0	17	5	-31.5	-42	22	42.8
2	30,000	1	8	0	0	2.5	90	5	4.9	0	59	59
2 a	30,000	1	8	15	0	2.5	90	5	1.9	0	19	19.1
3	30,000	2	6	15	0	0	17	5	-18	-36	7	41.2
4	30,000	2	6	10	0	0	17	5	-23	-27	-11	32.2
5	30,000	2	6	5	0	0	17	5	-25	-18	-12	27.2
6	30,000	2	6	0	2	0	0	5	4.9	-35	2.5	35.3
7	30,000	2	6	0	2	0	30	5	-15.3	-33	15	36.2
8	30,000	2	6	0	2	0	60	5	1.8	-25	21	48.8
9	30,000	2	6	0	0	2.5	90	5	2.3	-1	43	43.1
10	300,000	2	8	15	0	0	17	5	-25	-60	30	67
11	300,000	2	8	0	2	0	0	5	31	-75	6	81
12	300,000	2	8	0	2	0	0	10	34.5	-122	12	127
13	300,000	2	8	0	0	2.5	90	5	12.5	6	56	56.5

CANADIAN
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DRILLING
LIMITED

STRENGTH REQUIREMENTS FOR
NOZZLES FOR ICE
TRANSITING SHIPS

TITLE:
ICESIM RUNS SUMMARY

TABLE 7.1

Sensitivity analysis shows that:

Head-On Rammings

- The maximum force developed in the x direction diminishes with increased speed. This is due to the peculiarities of the nozzle intake shape and it is not expected to reflect full scale behaviour. The total load however grows with the speed.
- Large side-way forces can be developed due to the geometry of the nozzle's intake.
- The small single shaft ship (30,000 t) can develop a larger force on the nozzle than the large twin shaft ship, which is due to wing shaft eccentricity
- A head-on impact generates much smaller forces than a side impact due to the small contact area being developed.

Sideways Impact

Two knots "broadside slams", were executed for the two ships. The ice wall slope angle variation from 90° to 30° has shown a pronounced effect on the magnitude of the total ice force.

As expected, the horizontal force diminishes with the deviation of the wall angle from vertical.

The total force in the radial direction varied between 33 MN and 35 MN, for the 30,000 t ship and 75 MN for 300,000 t ship. Thus the total radial force doubled when the displacement rose tenfold.

Bottom Impact

The vertical impact force increased 30% for the tenfold increase of the displacement.

The centrally located nozzle on the smaller ship produced a 37% higher vertical force than the wing nozzle for the 30,000 t ship and 5% larger load then the wing nozzle on 300,000 t ship.

The high speed ahead bottom impact (Run #2a) produced a lower vertical force than when the ship was stationary.

Single Versus Twin Screw Arrangement

The difference between the radial forces generated during single and twin screw ship/ice impacts is due to two factors:

1. For the same horsepower, the single screw nozzle arrangement is larger (8 m versus 6 m diameter) and, consequently contact areas and forces are larger.

2. A centrally located single nozzle generates higher bottom impact loads as the ship cannot "roll-away" from the ice.

This difference is evident upon examination of Figure 7.3, from which it can be concluded that the maximum radial force grows with the displacement of the ship. The growth is faster for side impact than for bottom impacts.

The single shaft 30,000 t ship bottom impact generates a larger force than the twin shaft 300,000 t ship as the larger ship "rolls away".

Ice Strength

Two runs (#11 and #12) were executed in order to test the sensitivity of the maximum radial force to ice strength. The results are

ice strength, MPa	5	10
total max radial force, MN	75	123

Thus doubling of the ice strength leads to a 64% increase in force. This suggests that an ice strength to the power 0.75 should be used in the formulation of force as a function of the strength of ice.

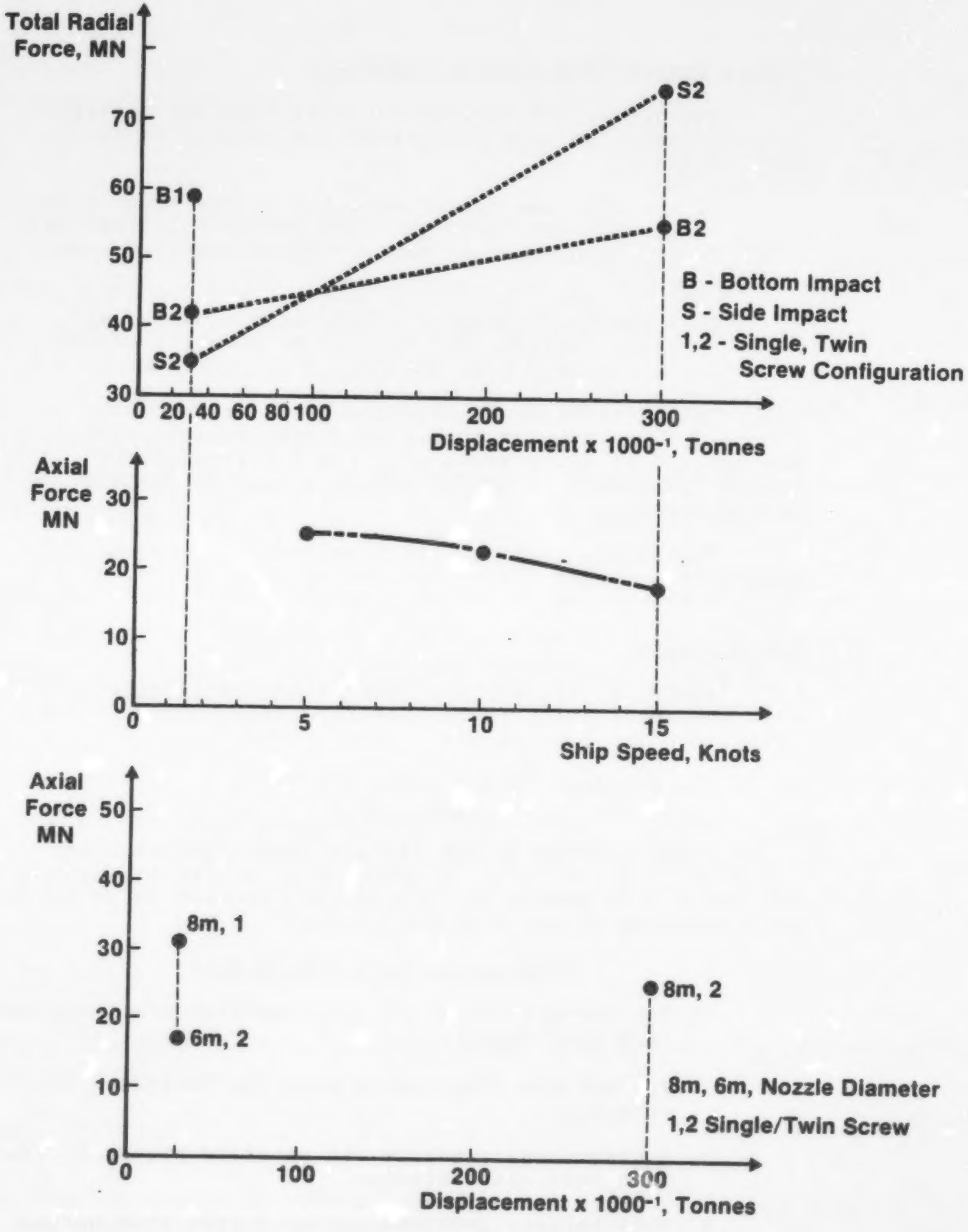
7.3 Conclusions from ICESIM Runs

1. The maximum radial force grows with the increased ship displacement.

2. The maximum force grows with the increased ice strength .

3. A single shaft nozzle can generate higher forces than twin shaft nozzles.

4. Side impacts generate higher forces than bottom impacts.



CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Sensitivity Analysis Of Icesim Runs FIGURE No. 7.3

This is particularily visible when comparing the following runs:

	Total Force, MN	
Run #11 (Side impact)	81	- 300,000 t ship
Run #13 (bottom impact)	56.5	- 300,000 t ship
Run #8 (Side Impact)	48.8	- 30,000 t ship
Run #9 (bottom impact)	43.1	- 30,000 t ship

5. Geometry and orientation of ice impacting the nozzle has a pronounced effect on the magnitude of ice forces.

6. For S.C.E. of 5 MPa, maximum forces were:

Axial direction	31.5 MN,
Radial direction	75.0 MN,

These forces are not to be used for the computation of stresses. They are indicative of the upper bound of interaction forces only.

Conclusions 1, 2 and 4 will be used in formulating recommendations for strength requirements for nozzles of ice transiting ships.

8. ANALYTICAL MODEL

8.1 Introduction

There are three basic tools available to the designer of a nozzle's structure:

- Handbook formulas;
- computer (2D or 3D FEM, etc.); and
- analytically derived formulations from first principles.

Handbooks (Ref. 8.1) offer ready to use formulations covering a majority of the cases to be considered. The methodology and derivations are not presented, however, to a degree which would satisfy a critical reader.

Computer modelling offers the advantage of covering those aspects of the nozzle's structural behaviour which do not lend themselves to analysis due to the mathematical complications involved. A disadvantage of the computer modelling is the the inherent lack of an insight into the correlation between input and output.

Analytical derivation of the nozzle's structural response to the load offers the following advantages:

- a complete understanding of the input-output parameters and their interdependance;

- a double-check of handbook formulae which might contain some discrepancies;

- a full control of the parameters involved in the modelling;

- ready to use formulations suitable for design work and regulatory purposes.

The disadvantages of analytical modelling are:

- Some repetition of the efforts already made elsewhere; and

- simplifications necessary for the sake of manageability of the analysis.

After a detailed investigation of the three options, it was decided to use all 3 of them as follows:

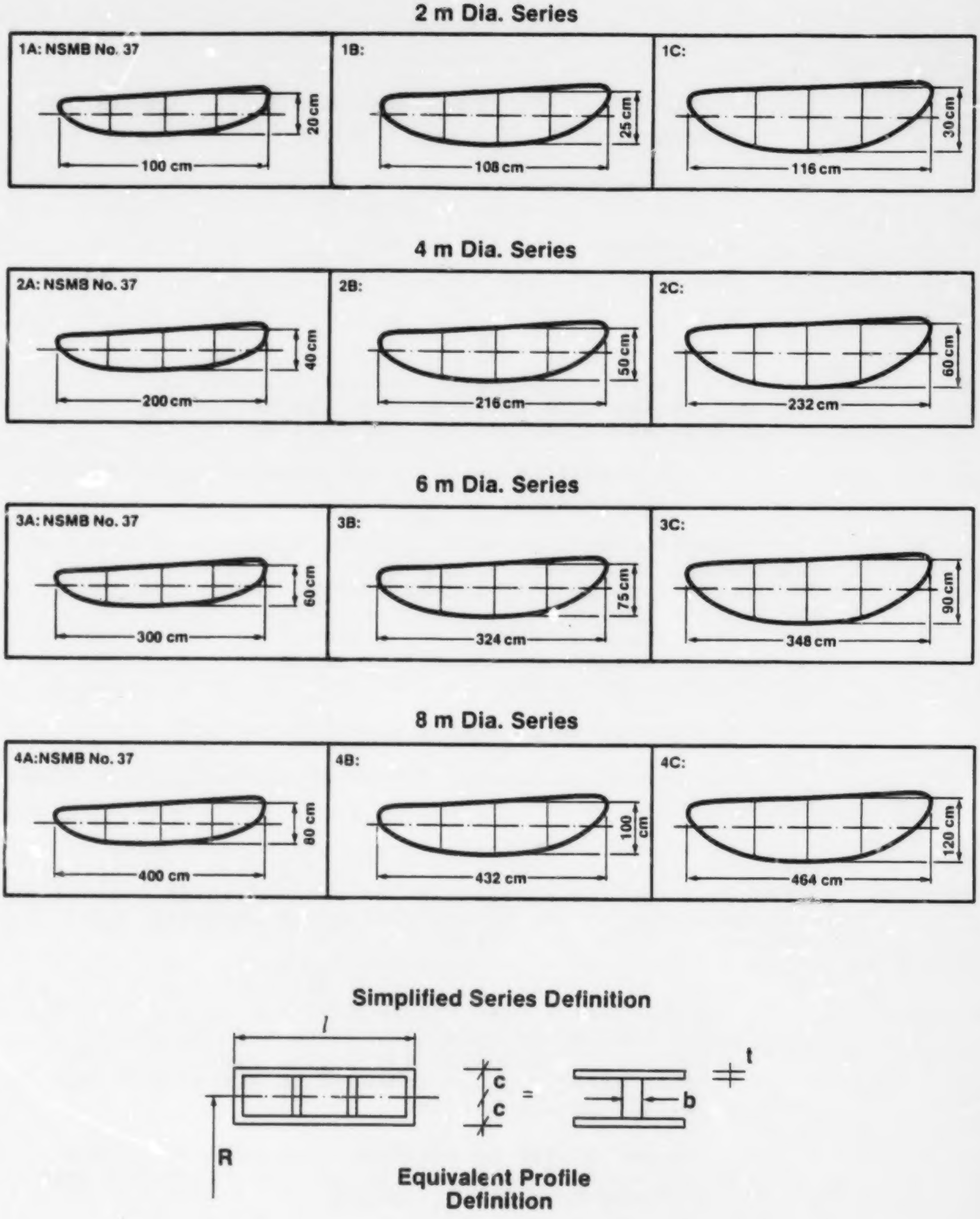
- The analytical derivation of the nozzle's structural response from first principles will be the primary modelling tool.
- These derivations will be checked against handbook formulations to assure their correctness.
- Further, the handbook formulations will be used for those issues which are not covered by the simplified analysis (influence of the load application angle, influence of load spread).
- Finally a computer model will be built in order to examine those effects which are not covered by the preceeding methods, such as:
  - local strength,
  - torsion effect,
  - non-uniformity of material distribution,
  - thickness effect,
  - foundation stiffness effect.

A comparison of these methods will be made for the sake of deriving the most benefits from all of them, and assuring the highest possible generality of the proposed formulations.

8.2 Sketch Design Of Nozzle Series

In order to assess the general structural properties of the nozzles, present and future, a series of them was designed, covering the whole range of possible applications. As it was realized from the onset of the study that the existing nozzle strengths may not be sufficient to carry the ice loads, an investigation into the effects of the increase of profile thickness was made. Details of that research are given in Appendix D. The main finding of it was that a moderate increase of the nozzle profile thickness (an increase of s/ℓ ratio) is an efficient and acceptable way of increasing the section modulus of the nozzle. Consequently the designed nozzle series reflects this finding. The scantlings of plates were chosen to be the same or higher then those for the sterns of ice going ships. The geometry of the nozzle series is shown on Figure 8.1.

The basic nozzle profile chosen was NSMB #37, since it has been commonly used for open water applications. There are 3 basic shapes, with different profile thickness to length ratios:


2 m Dia. Series
1A: NSMB No. 37
20 cm
100 cm
1B:
25 cm
108 cm
1C:
30 cm
116 cm
4 m Dia. Series
2A: NSMB No. 37
40 cm
200 cm
2B:
50 cm
216 cm
2C:
60 cm
232 cm
6 m Dia. Series
3A: NSMB No. 37
60 cm
300 cm
3B:
75 cm
324 cm
3C:
90 cm
348 cm
8 m Dia. Series
4A:NSMB No. 37
80 cm
400 cm
4B:
100 cm
432 cm
4C:
120 cm
464 cm
Simplified Series Definition
l
R
c
c
=
b
t
Equivalent Profile Definition

CANADIAN
MARINE
DRILLING
LIMITED

Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Nozzle Series Geometries

FIGURE No. 8.1

SERIES DESIGNATION	THICKNESS/LENGTH RATIO (s/ℓ)	LENGTH/DIA. RATIO (ℓ/D)
A (Basic)	.20	.5
B	.23	.54
C	.26	.58

ℓ/D ratio was somewhat changed in order to accommodate the same curvatures on the intakes and outlets of the nozzles for all of the thicknesses.

The principal structural characteristics of this nozzle series are given in Table 8.1.

Inspection of Table 8.1, shows that the increase of thickness/length ratio from 0.20 to 0.26 (30%) leads to a 79% increase of section modulus. Thus the increasing of the profile thickness is a very effective way of increasing the strength of the nozzle ring. The influence of the increase of nozzle profile thickness on hydrodynamic performance is discussed in the Appendix D.

8.3 Nozzle Structural Properties

The strength characteristics of the series are shown in Figure 8.2

In order to develop a simple analytical model of the nozzle's structural response to the ice load a structural arrangement of the nozzle must be reduced to an equivalent beam ameanable to the analysis. Such a reduction is obtained through the following steps:

- The nozzle section profile is simplified to form a "box" girder (see Figure 8.1) having the length of the nozzle and height equal to mean height of the profile. The intake and outlet curvatures are "flattened" out and included in either the skin plating or web plating.
- The box girder so obtained, having 4 or 5 webs (including 2 external) is subject to curved beam analysis in order to assess:

- shear influence,
- hoop stress influence,
- stress eccentricity.

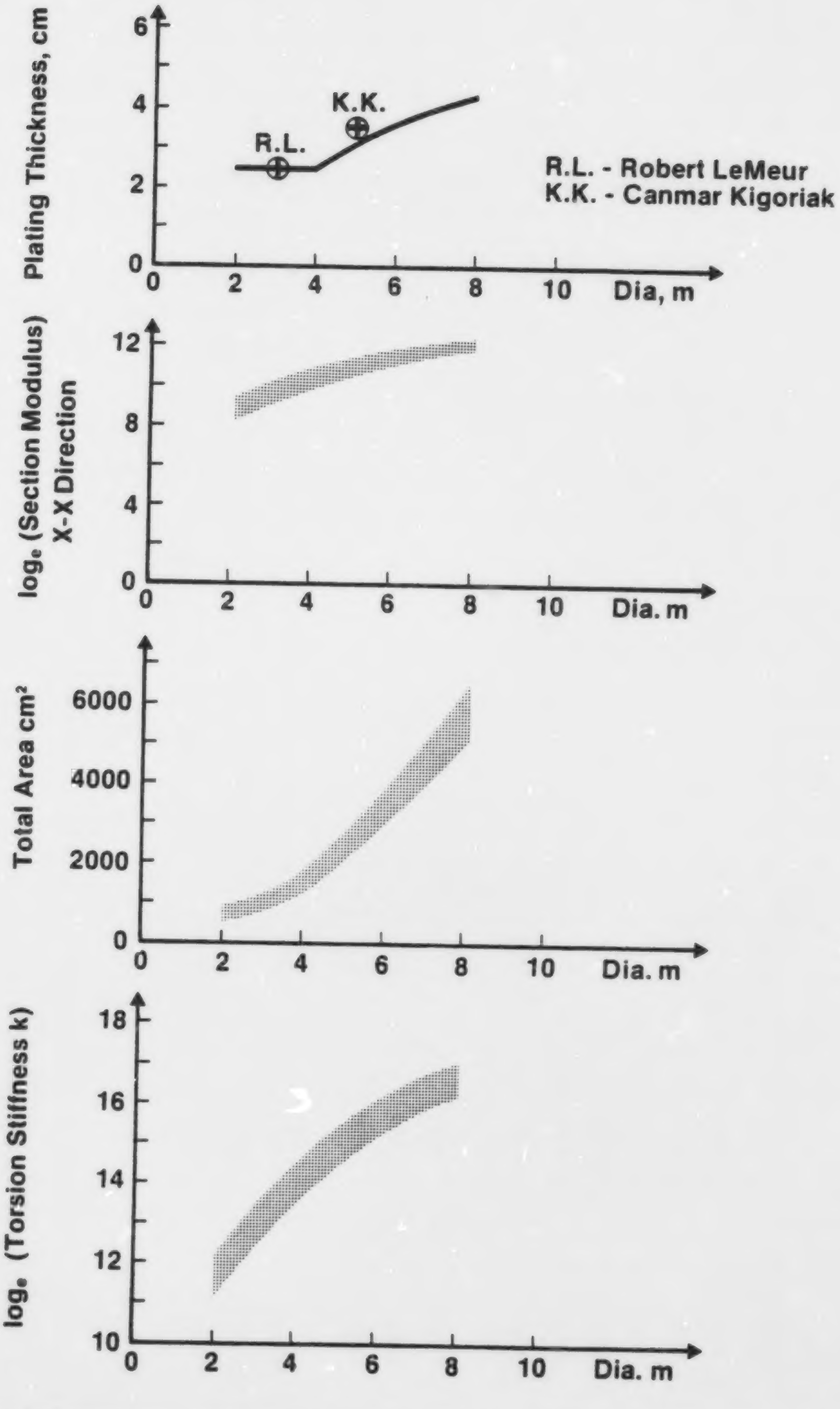
NOZZLE	VESSEL DISPLACEMENT TONNES	NO. OF PROPS	SHP PER PROP	PROP DIA. METERS	NOZZLE MATER'L	PROFILE LENGTH CM	PROFILE THK'S CM	SHELL THK'S CM	NUMBER OF WEBS	WEB THK CM	LONG'L SPG CM	AREA X-X CM^2	AREA Y-Y CM^2	TOTAL AREA CM^2	MODULUS X-X CM^3	MODULUS Z-Z CM^3
1A	2000	2	2000	2	EH36	100	20	2.5	4	2.5	30	200	500	700	5666	15000
1B	2000	2	2000	2	EH36	108	25	2.5	4	2.5	30	250	540	790	7791	18720
1C	2000	2	2000	2	EH36	116	30	2.5	4	2.5	30	300	580	880	10200	22813
2A	10000	2	8000	4	EH36	200	40	2.5	4	2.5	30	400	1000	1400	22666	60000
2B	10000	2	8000	4	EH36	216	50	2.5	4	2.5	30	500	1080	1580	31166	74880
2C	10000	2	8000	4	EH36	232	60	2.5	4	2.5	30	600	1160	1760	40800	91253
3A	30000	2	20000	6	EH36	300	60	3.6	4	3.6	30	864	2160	3024	73440	194400
3B	30000	2	20000	6	EH36	324	75	3.6	4	3.6	30	1080	2333	3413	100980	242611
3C	30000	2	20000	6	EH36	348	90	3.6	4	3.6	30	1296	2506	3802	132192	295660
4A	300000	2	50000	8	EH36	400	80	4.2	5	4.2	30	1680	3360	5040	156800	393000
4B	300000	2	50000	8	EH36	432	100	4.2	5	4.2	30	2100	3629	5729	216440	488073
4C	300000	2	50000	8	EH36	464	120	4.2	5	4.2	30	2520	3898	6418	284256	593734

Notes:

1. Area X-X denotes effective shear area of vertical members of nozzle profile section.
2. Area Y-Y denotes effective shear area of horizontal members of nozzle profile section.
3. Number of webs includes leading and trailing edge plating.
4. Modulus X-X denotes section modulus about longitudinal axis of the nozzle section.
5. Modulus Z-Z denotes section modulus about vertical axis of the nozzle section.
6. All numbers are based on the simplified profile having rectangular shape.

TITLE:
PRINCIPAL STRUCTURAL CHARATERISTICS
OF THE NOZZLE SERIES

TABLE 8.1



CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Nozzle Series Strength Parameters FIGURE No. 8.2

The above checks are required to assess how different is the behaviour of the actual beam-ring from the thin curved beam acting in flexure only.

Checks are performed using Ref. 8.1 with the inputs defined in Table 8.1.

8.3.1 Shear Stress Influence

Is assessed through the evaluation of the transverse shear deformation factor β, defined as:

$\beta = FEI/GAR^2$, where,

F = Shape factor for a given section profile,
I = Inertia of section,
E = Young's modulus,

G = Shear modulus of elasticity,
A = Cross sectional area,
R = Mean radius of the curvature of the ring.

F is calculated for a box girder section having plating and web thicknesses equal and constant throughout the section (after Ref. 8.2):

$$F = [1 + 3D_1 (D_2^2 - D_1^2)/2D_2^3 (t_2/t_1 - 1)] \times 4D_2^2/10r^2$$

where:

D_1 = Distance from neutral axis to the nearest surface of flange,
D_2 = Distance from neutral axis to extreme fiber
t_1 = Thickness of web,
t_2 = Width of flange,
$r^2 = I/A$ = (radius of gyration)^2 of the section with respect to the neutral axis.

Results of the computations of shear deformation factor β are presented in Table 8.2.

NOZZLE	SHEAR DEFORMATION COEFFICIENT β	TANGENTIAL FORCE DEFORMATION COEFFICIENT α	STRESS MULTIPLIER	
			K_{IN}	K_{OUT}
1A	0.065	0.0067	1.035	0.969
1B	0.087	0.0097	1.042	0.964
1C	0.111	0.0131	1.048	0.958
2D	0.069	0.0067	1.027	0.976
2B	0.091	0.0097	1.033	0.970
2C	0.115	0.0131	1.040	0.965
3A	0.069	0.0067	1.027	0.976
3B	0.091	0.0097	1.033	0.970
3C	0.115	0.0131	1.040	0.965
4A	0.057	0.0064	1.028	0.974
4B	0.076	0.0093	1.036	0.969
4C	0.096	0.0125	1.043	0.962
KIG[1]	0.049	0.0051	1.026	0.976
RL[2]	0.055	0.0064	1.032	0.971
S1&2[3]	0.056	0.0077	1.036	0.967
S7[4]	0.119	0.0082	1.021	0.981
MVA[5]	0.043	0.0031	1.016	0.985

1. Canmar Kigoriak
2. Robert LeMeur
3. Supplier 1 and 2
4. Supplier 7
5. Arctic

TITLE:
NOZZLE RING STRENGTH COEFFICIENTS

TABLE 8.2

The following points are worth noting:

- Shear deformation factor is small ($\beta < .12$) which proves that nozzle beam-ring will work primarily in flexure and shear deformations can be ommited.
- Influence of shear grows rapidly with the thickening of the nozzle (doubles for nozzle 1C versus 1A).
- Increase of web area (Series 4) reduces the influence of shear on the response of the nozzle ring.

8.3.2 Tangential Force (hoop force) influence

is measured by the α coefficient, defined as:

$$\alpha = (r/R)^2$$

where:
r = is the radius of gyration of a cross section; and
R = mean radius of the nozzle's ring.

Results of computations for the series are also presented in Table 8.2. It shows that:

- Influence of tangential deformation on the ring response is negligible, as the α coefficient is very small ($\alpha < 0.013$). This influence may become important when $\alpha > 0.10$.
- Increase of the ring profile thickness rapidly increases the α coefficient.

8.3.3 Stress Multipliers

The distribution of stresses due to bending in the nozzle's section is hyperbolic, due to the curvature of the ring. In order to assess the influence of this curvature on the magnitude of the stresses in inner and outer-most fibres, stress multipliers are computed, following the procedure in Ref. 8.1. These multipliers reflect the ratio of the actual stress in curved beams to the stresses computed as if those beams were straight (i.e. ratio of hyperbolic to straight stress distribution across the section).

Results given in Table 8.2 show that:

- the outer fiber stress multiplier K_{out} varies from 0.958 to 0.976,
- the inner fiber stress multiplier K_{in} varies from 1.027 to 1.048,
- the greater the nozzle section thickness, higher the non-linearity of the stress distribution.
- larger nozzles have more linear stress distribution than smaller nozzles.
- for small and medium size nozzles, the non-linearity of stress distribution must be taken into account.

Consequently, the stress multipliers will be accounted for in the analysis.

Two more curved-beam parameters must be checked, both related to the stress eccentricity:

- location of the neutral axis, and
- effective curved flange width.

Ref. 8.1 gives the following formulation for the distance ε between the middle of the symmetrical section and the neutral axis:

$$\varepsilon = R_o + h/2 - A_\otimes / [\ell * \ln * (((1+t/R_o)/(1-(t/R_o)/(1+h/R_o))) + nt * \ln ((1+h/R_o - t/R_o)/(1+t/R_o))]$$

where:

$A_\otimes$ = the area of the ring section,
ℓ = the length of the section,
t/R_o = the plating thickness/radius ratio,
h/R_o = the profile thickness/radius ratio,
n = the number of webs,
t = the plating thickness, and
ln = natural logarithm

For the smallest nozzle design (1A), the non-dimensional eccentricity was found to be 7% of the radius; for the largest nozzle (4C) it was found to be 2%.

These eccentricities are small, and due to the cumbersome nature of the formulation, will not be used for this study. A detailed design of the nozzle should, however, account for it.

Effective flange width b^1 is given (Ref. 8.1) as a function of the parameter qb, defined as:

$$qb = [3(1-\nu^2)(\bar{b})^4/R_o^2 t^2]^{1/2}$$

where $\bar{b}$ is the unsupported width of the real flange and the other variables were defined previously.

For nozzle 1A, we find:

$qb = 2.3$ and correspondingly $b^1/\bar{b} \cong 0.75$

For the nozzle 4C, we have:

$qb = 3.22$ and $b^1/\bar{b} \cong 0.55$

Thus a detailed design of the nozzle should account for the effective flange width while calculating the stresses. The above corrections apply to the unsupported flanges only. In reality, the flanges are supported transversely and, it is expected that the effective flange widths are much larger than those calculated above. As the study has a comparative character only, we are not using this correction. However, the test of effectiveness of flanges will be made by comparing the FEM calculated stresses with those computed analytically without the correction for the effective width of the flange.

8.4 Assumptions, Principles And Methods Used In The Analysis

8.4.1 Loading Related Assumptions

1. Ice load is the only load acting on the nozzle ring during the interaction. Other loads, including:

- hydrostatic pressure head,
- hydrodynamic propeller induced pressures,
- inertia of the nozzle,

are negligible in comparison with ice load and are excluded from the calculations.

2. The ice load is static in nature, i.e. the time of the load application is long in comparison with the ring's response time in the lowest mode of vibrations.

3. The ice load is distributed uniformly along the length of the nozzle and the "load strip" is parallel to the nozzle's axis of symmetry.

4. The load is perpendicular to the outer surface at any point (i.e. friction forces are not present).

5. The load used in the analysis is a "unit load" of a magnitude of 1.

8.4.2 Nozzle's Structural Response Assumptions

1. The response is static, i.e. not dependant on vibratory properties.

2. The response is in the linear domain, i.e. proportionality of stresses and strains is maintained.

3. The deformations of the ring are small and are not affecting the ring's geometry. For a discussion of buckling, see section 8.12.

4. The actual nozzle structure is reduced to a simple box-beam, having properties as defined in Table 8.1.

5. The nozzle's material is assumed to have the following characteristics:

Yield Strength $\sigma_y = 3.6 \cdot 10^8$ Pa, Shear Strength $\tau_y = 1.8 \cdot 10^8$ Pa,

Elastic Modulus $E = 2.1 \cdot 10^{11}$ Pa,

Poisson Ratio $\upsilon = 0.29$.

8.4.3 Principles used for the analysis

As a nozzle-ring supported at the upper end forms a statically indeterminate structure, the first principle of Castigliano is used in determination of reaction forces and moments. This principle is fully explained in Ref. 8.2, listed at the end of chapter 8.

The second important principle involved is the principle of super-position, i.e. the nozzle's response to a number of loads can be calculated by adding up the responses to individual loads.

8.4.4 Method Used

For a given nozzle-support configuration, and loading condition, the analysis was performed following the steps:

1. An expression for the bending moment distribution along the nozzle's ring was derived $M = M(\varphi)$, where φ is the angular location of the section (see Fig 8.3 for definitions). This function is dependent on the foundation geometry and the location of the load.
2. Strain energy in flexure was then obtained using the expression:

$$U = \int_0^{2\pi-2\Theta} M^2(\varphi)\, R\, d\varphi / 2EI$$

Only the energy of flexure needs to be considered, as shown in the preceeding paragraphs.

3. The unknown reactions were then determined using Castigliano's theorem, i.e.:

$$\partial U/\partial(\text{reaction}) = 0 \quad \text{for reaction forces}$$

The above general equation yields a set of equations (Ref 8.2), the number of which is equal to the number of statically indeterminate reaction forces.

4. A solution of the set of equation gives the reaction forces as a function of the nozzle support geometry and the point of application of the load.

5. Having determined all of the unknown variables, the required expressions for:

Bending moment	BM [Nm]
Shear Force	SF [N]
Tangential Force	TF [N]
Deformations	δ [m]

are found as a function of:

- nozzle support angle Θ,
- force application angle α, and
- angular location of the section coordinate φ

In the analysis, non-dimensional quantities are handy to use, which we will define as:

Bending Moment Coefficient:

C_{BM} = Bending Moment/F x R

Shear Force Coefficient:

C_{SF} = Shear Force/F

Tangential Force Coefficient:

C_{TF} = Tangential Force/F

Deflection Coefficient:

C_{δ} = Deflection/(FR^3/EI)

Note that all of the above coefficients do not depend on the actual size of the nozzle. For example, for a given foundation angle and point of force application, C_{BM} has the same value for a nozzle 2 m or 8 m in diameter. The magnitude of the stresses, however, do depend on the size of the nozzle. For example:

$$\sigma_{BM} = BM/Z = (F \times R \times C_{BM})/Z \quad (C_{BM} = f\ (\Theta, \alpha, \varphi))$$

From the above the maximum force causing the maximum bending stress can be calculated:

$$F_{max} = ((\sigma_{BM})max \times Z)/R \,.\, C_{BM}$$ (see page 121).

The expressions for bending moment, shear force, tangential force and deflections are defined as follows:

BM (φ, Θ, α) from the geometry of nozzle and load

SF = $d[BM(\varphi, \Theta, \alpha)]/Rd\varphi$

$$TF = \frac{dSF}{d\varphi}$$

$$\delta_N(\varphi) = \int_0^{\varphi} \frac{BM(\varphi)}{EI} R^2 \sin(\varphi - \xi)\, d\xi \qquad \text{(Ref 8.2)}$$

$$\delta_T(\varphi) = \int_0^{\varphi} \frac{BM(\varphi)}{EI} R^2 [1 - \cos(\varphi - \xi)]\, d\xi$$

where δ_N denotes the displacement of the nozzle's ring in the direction normal to the surface, and δ_T denotes the displacement of the nozzle's ring in the direction tangential to the surface (see Figure 8.3). Total displacement at any point is then:

$$\delta_{tot} = (\delta_N^2 + \delta_T^2)^{1/2}$$

Figure 8.3 shows the symbols used in the analysis.

6. Having defined the bending moment, shear force and axial force, the calculation of stress in the extreme fibers is performed using the formulae:

$\sigma_{total} = \sigma_{BM} \pm \sigma_{TF}$, where

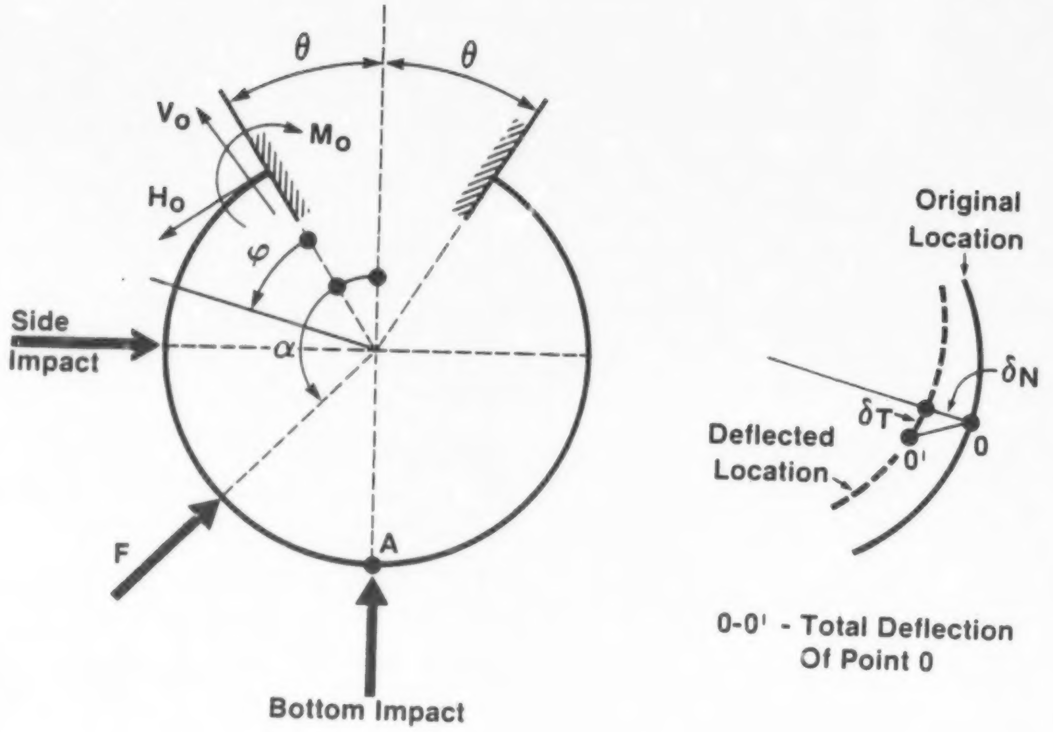
$\sigma_{BM} = BM(\varphi)max/Z$, and

$\sigma_{TF} = TF/A$

as is the case for straight beams. The stress component due to shear, i.e.:

$\tau = (SF/A)K$ (K is the shear stress shape factor.)

* Where ξ is the running coordinate between the foundation point and the point under investigation φ.


θ
θ
Vo
Mo
Ho
φ
Side Impact
α
F
A
Bottom Impact
Original Location
δN
δT
Deflected Location
0'
0

0-0' - Total Deflection Of Point 0

θ - Half Of The Total Foundation Angle
φ - Angle at Which BM, SF, TF is evaluated
α - Angle Of Load Application

Vo, Ho, Mo } Normal Force,Tangential Force and Bending Moment at Nozzle Support

V_A, H_A, M_A } Normal Force, Tangential Force and Bending Moment At Point A

R - Nozzle's Radius (mean)
F - Force Applied
BM - Bending Moment ↻⊕
SF - Shear Force ↑⊕↓
TF - Tangential →⊖←

CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Definitions Used In The Text FIGURE No. 8-3

is omitted, as the maximum shear stress does not occur at the location of the maximum bending stress.

However, the check for a combined stress at the middle of the section is performed, i.e.

$$\sigma_C = 1/2\ ((4\tau_{SF}^2 + \sigma_{TF}^2)^{1/2} \pm \sigma_{TF})$$

7. Knowing the elastic limit of the nozzle's material, the minimum force causing either:

$\sigma_T = \sigma_{yield}$ (tensile/compressive stress due to combined bending and normal force)

$\tau = \tau_{yield}$ (shear strength limit)

$\sigma_c = \sigma_{yield}$ (combined stress limit)

$\delta/R = 0.01$ (deflection limit based on 1% propeller tip clearance)

is defined for all of the nozzles in question.

8.5 Detailed Analysis Of Side Impact

Geometry dictates the expression for the bending moment:

$$BM(\varphi) = Mo - HoR\ (1 - \cos\varphi) - VoR\sin\varphi + FR\sin(\varphi - (\pi/2 - \theta))$$

See Figure 8.3 for definitions.

and

$\partial M/\partial Mo = 1,$

$\partial M/\partial HoR = \cos\varphi - 1$

$\partial M/\partial VoR = -\sin\varphi$

The equations obtained using Castigliano's first theorem are:

$$Mo(2\pi-2\theta) - HoR[2\pi-2\theta+\sin2\theta] + VoR(\cos2\theta-1) = -FR(1+\sin\theta)$$

$$-Mo(2\pi-2\theta+\sin2\theta) + HoR(3\pi-3\theta+2\sin2\theta - (\sin4\theta)/4) + VoR\ 2\sin\theta$$
$$= FR\ ((3\pi/4 - \theta/2)\cos\theta + \sin^3\theta+1)$$

$$Mo(\cos2\theta-1) + 2HoR\sin^4\theta + VoR(\pi-\theta + (\sin4\theta)/4)$$
$$= FR/4(\cos3\theta + \cos\theta + (3\pi - 2\theta)\sin\theta).$$

The solution of this set of 3 equations in general form is feasible but cumbersome. Consequently, the numerical values of θ were used first and then equations were solved for Mo, Vo and Ho.

Solution of the equations gives the following values of the unknown reactions in non-dimensional form (as defined on page 66):

θ°	C_{BM}	C_{TF}	C_{SF}
0	.591	.750	.159
15	.556	.706	.343
30	.498	.631	.507
45	.418	.529	.654

θ°	C_{BM}	C_{TF}	C_{SF}
60	.324	.402	.797
75	.204	.234	.931
90	0	0	1

The total foundation reactions are given below:

θ^o	R_L 1	R_R 2	R_{tot} 3	$(C_{BM})_L$ 4	$(C_{BM})_R$ 5	$(C_{BM})_{tot}$ 6
0	.766	.296	1	.591	.409	1.00
15	.785	.380	1	.556	.333	.889
30	.809	.235	1	.498	.244	.742
45	.841	.186	1	.418	.164	.582
60	.892	.220	1	.324	.090	.414
75	.960	.043	1	.204	.026	.230
90	1.000	.000	1	0	0	0

Subscripts 1 to 6 are:

1. Nondimensional reaction force at left support.
2. Nondimensional reaction force at right support.
3. Nondimensional total reaction force, projected on horizontal plane.
4. Bending moment coefficient at left support.
5. Bending moment coefficient at right support.
6. Bending moment coefficient total.

The following observations can be made regarding the reactions:

- The larger the foundation angle Θ, the smaller the total reaction bending moment is.

- The larger the angle Θ, the more loaded (both force and bending movement wise) becomes the foundation structure at the side closer to the load application point.

- The left hand reaction R_L grows, and R_R diminishes with the increase of angle Θ, (force being applied on the left hand side).

- With the total reaction force being constant, one side of the foundation structure becomes more loaded as regards reaction force with the increase of the foundation angle Θ.

Bending moments, shear forces, axial forces and deformation distributions along the ring are given in Table 8.3.

Figures 8.4 and 8.5 depict some of the distributions.

The following points are worth noting:

Bending Moment Distribution

- Maximum negative bending moments occur at the foundation point nearer to the force.

- Maximum positive bending moments occur at the right hand foundation point or in between the left foundation point and the point of load application.

θ \ φ	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360
0	-.591	-.524	-.411	-.259	-.078	+.118	+.318	+.248	+.172	+.095	+.022	-.041	-.091	-.124	-.137	-.130	-.104	-.059	0	+.070	+1.46	+.223	+.296	+.359	+.409
15	-.556	-.443	-.290	-.107	+.094	+.298	+.234	+.164	+.093	+.026	-.033	-.079	-.110	-.123	-.117	-.093	-.053	-.014	+.066	+.136	+.207	+.274	+.333	-	-
30	-.498	-.345	-.160	+.045	+.256	+.200	+.140	+.079	+.021	+.028	-.067	-.092	-.102	-.096	-.074	-.038	+.009	+.065	+.126	+.187	+.244	-	-	-	-
45	-.418	-.231	-.020	+.20	+.154	+.106	+.058	+.014	+.024	-.052	-.070	-.075	-.067	-.047	-.017	+.023	+.067	+.116	+.164	-	-	-	-	-	-
60	-.324	-.104	+.128	+.098	+.067	+.036	+.009	+.014	-.031	-.040	-.041	-.034	-.02	+.001	+.028	+.057	+.09	-	-	-	-	-	-	-	-
75	-.204	+.045	+.034	+.023	+.012	+.002	-.005	-.010	-.13	-.012	-.009	-.003	+.005	+.015	+.026	-	-	-	-	-	-	-	-	-	-
90	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-

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STRENGTH REQUIREMENTS FOR NOZZLES
FOR ICE TRANSITING SHIPS

TITLE:
BENDING MOMENT DISTRIBUTION ALONG THE RING
C_{BM} COEFFICIENT

TABLE 8.3

0	-.159	-.347	-.512	-.643	-.729	-.765 -.771	-.75* .25	.283	.296	.289	.262	.218	.159	.089	.013	-.064	-.137	-.200	-.25	-.283	-.296	-.289	-.263	-.218	-.159
15	-.343	-.514	-.650	-.741	-.783* -.800	+.229	.26	.273	.267	.243	.203	.148	.084	.014	-.057	-.124	-.183	-.229	-.26	-.273	-.267	-.243	-.203	-	-
30	-.507	-.653	-.754	-.805* -.836	+.200	+.225	.234	.229	.207	.171	.123	.067	.007	-.054	-.111	-.161	-.200	-.225	-.235	-.229	-.207	-	-	-	-
45	-.654	-.768	-.831	+.163	.181	.186	.178	.158	.128	.088	.043	-.005	-.053	-.097	-.135	-.163	-.181	-.186	-.178	-	-	-	-	-	-
60	-.797	-.874	-.891	.152	.22	.271	.305	.318	.309	.279	.230	.166	.089	.008	-.075	-.152	-.22	-	-	-	-	-	-	-	-
75	-.931	-.96	.043	.042	.039	.033	.025	.015	.004	-.007	-.018	-.027	-.034	-.040	-.043	-	-	-	-	-	-	-	-	-	-
90	-1.00	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-

* Shows Discontinuity of Shear Force Value at Point of Load Application

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STRENGTH REQUIREMENTS FOR NOZZLES
FOR ICE TRANSITING SHIPS

TITLE:
SHEAR FORCE DISTRIBUTION ALONG THE RING
C_{SF} COEFFICIENT

TABLE 8.3 (CONT'D.)

TANGENTIAL FORCE DISTRIBUTION ALONG THE RING

C_{TF} COEFFICIENT

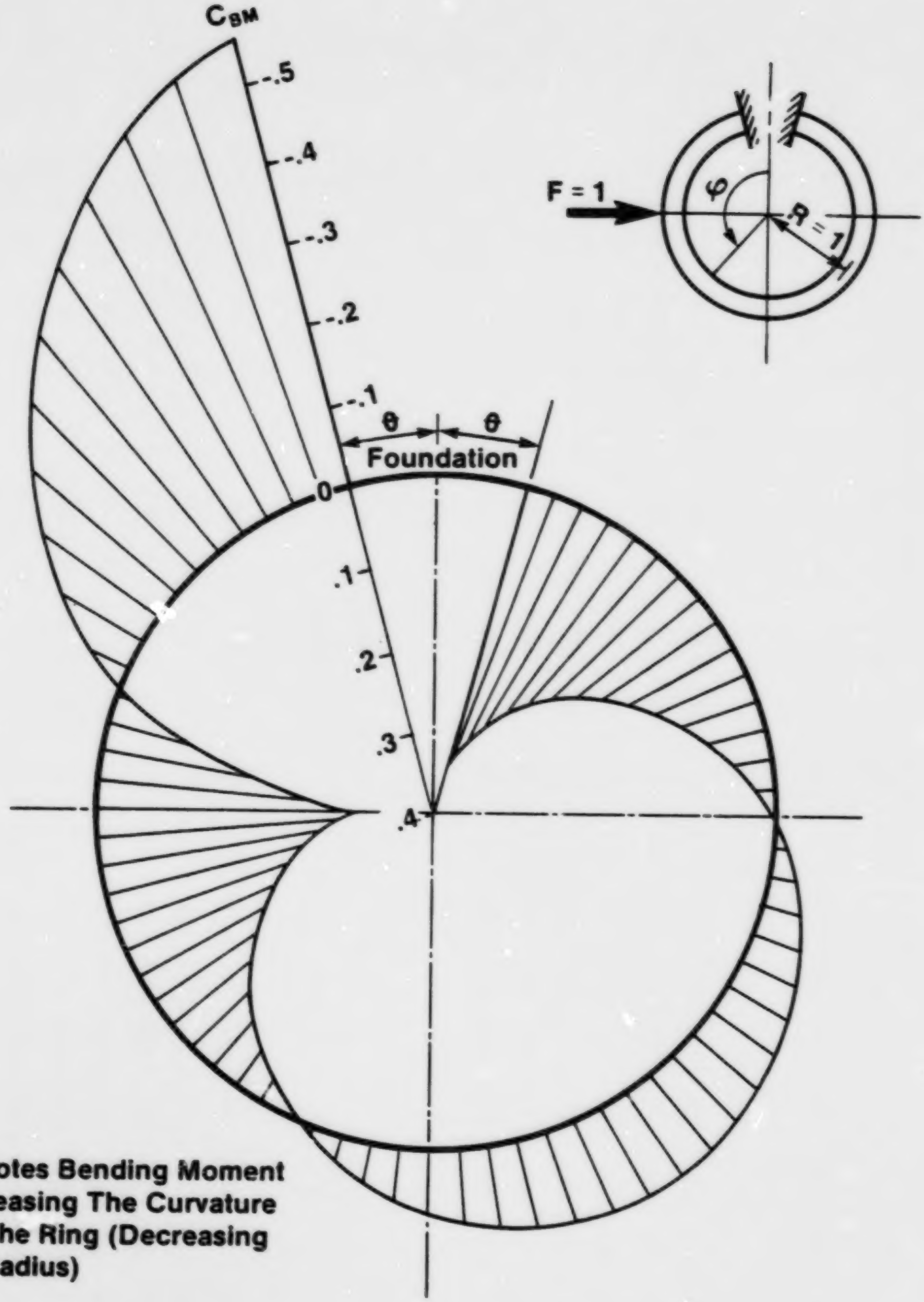
θ \ φ	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360
0	-.75	-.683	-.570	-.418	-.237	-.040	+.159	+.089	+0.13	-.064	-.137	-.200	-.250	-.283	-.296	-.289	-.263	-.218	-.159	-.089	-.127	+.064	+.137	+.200	+.25
15	-.706	-.593	-.440	-.257	-.056	+.148	+.084	+.014	-.057	-.124	-.183	-.229	-.260	-.273	-.267	-.243	-.203	-.148	-.084	-.014	+.057	+.124	+.183	-	-
30	-.631	-.478	-.293	-.087	+.124	+.067	+.007	-.054	-.111	-.161	-.200	-.225	-.235	-.229	-.207	-.171	-.123	-.067	-.007	+.054	+.111	-	-		
45	-.529	-.342	-.131	+.088	+.043	-.005	-.053	-.097	-.135	-.163	-.181	-.186	-.178	-.158	-.128	-.088	-.043	+.005	+.053	-	-				
60	-.402	-.182	+.050	+.020	-.011	-.041	-.069	-.092	-.109	-.118	-.119	-.112	-.098	-.077	-.050	-.020	+.011	-	-						
75	-.234	+.015	+.004	+.007	-.018	-.027	-.033	-.040	-.043	-.042	-.039	-.033	-.025	-.015	-.004	-	-								
90	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-										

NORMAL DEFLECTION ALONG THE RING

$C_{\delta N}$ COEFFICIENT

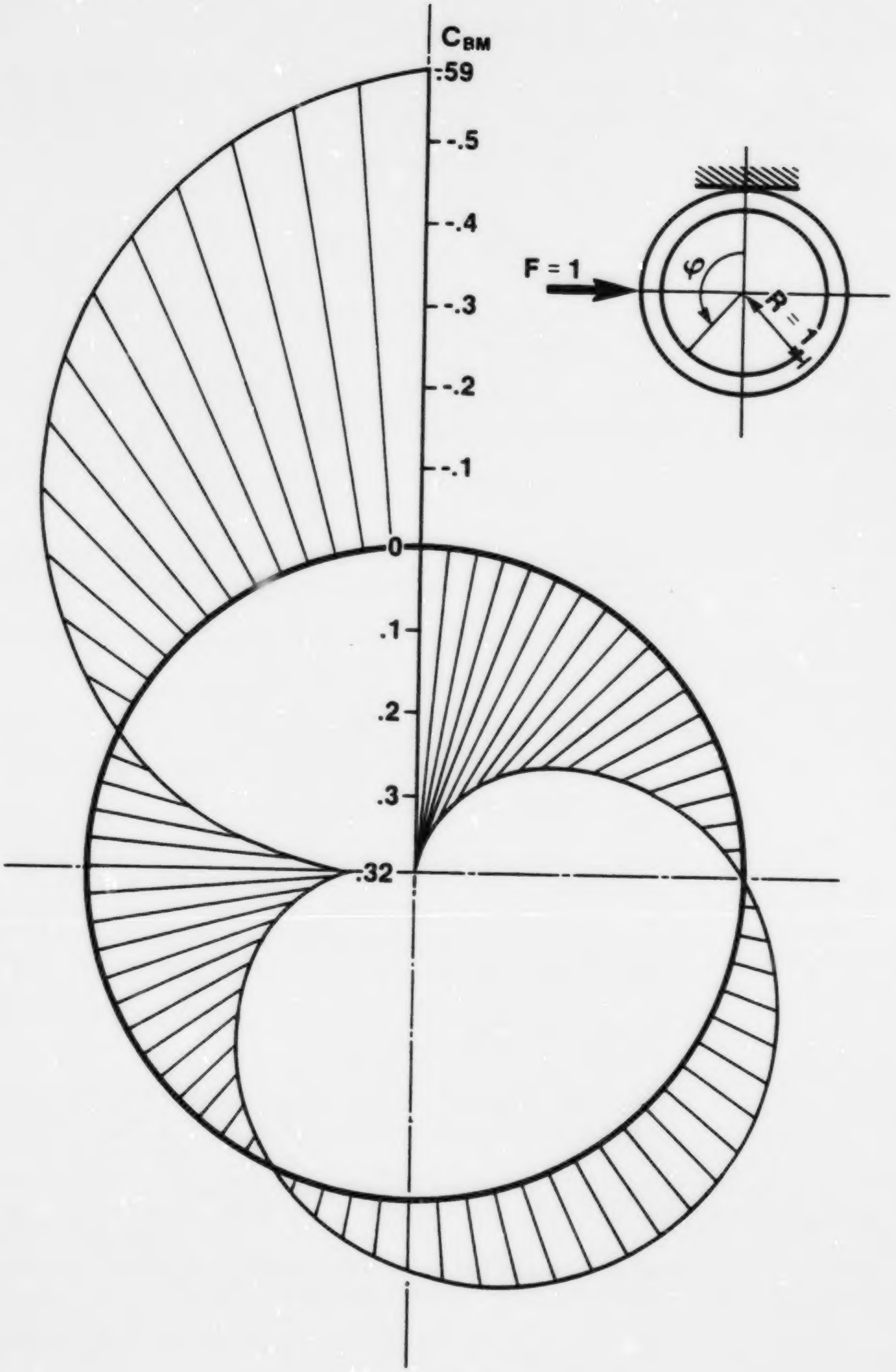
θ \ φ	0	15	30	45	60	75	90	105	120	135	150	165	180	195	210	225	240	255	270	285	300	315	330	345	360
0	0	.019	.073	.150	.233	.306	.350	.352	.313	.240	.145	.039	-.07	-.163	-.240	-.291	-.313	-.307	-.27	-.226	-.166	-.104	-.051	-.014	.000
15	0	.0178	.064	.126	.187	.228	.236	.212	.163	.96	+.021	-.053	-.119	-.169	-.199	-.208	-.196	-.167	-.128	-.084	-.043	-.014	.000	-	-
30	0	.0153	.053	.098	.133	.143	.132	.102	.059	+.010	-.037	-.077	-.106	-.120	-.121	-.107	-.085	-.056	-.209	-.008	.000	-	-	-	-
45	0	.012	.039	.065	.075	.070	+.053	.029	.001	-.025	-.046	-.059	-.063	-.058	-.046	-.03	-.013	-.005	.000	-	-	-	-	-	-
60	0	.008	.024	.031	.030	.022	.0104	-.003	-.015	-.024	-.028	-.028	-.024	-.017	-.009	-.002	.000	-	-	-	-	-	-	-	-
75	0	.004	.008	+.009	+.008	+.005	+.002	-.001	-.003	-.004	-.004	-.003	-.002	-.001	.000	-	-	-	-	-	-	-	-	-	-
90	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-	-	-	-	-	-	-	-	-

CANADIAN MARINE DRILLING LIMITED	STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS	TITLE: TANGENTIAL FORCE DISTRIBUTION ALONG THE RING TABLE 8.3 (CONT'D)



(-) Denotes Bending Moment Increasing The Curvature Of The Ring (Decreasing Its Radius)

CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	Side Impact Bending Moment Distribution For θ = 15°
		FIGURE No. 8.4



Side Impact Bending Moment Distribution For θ = 0°

FIGURE No. 8.5

- an average bending moment is a measure of global flexing of the nozzle ring. It is defined as:

$$BM_{AV} = \int_{0}^{2\pi-2\Theta} BM(\varphi)\, d\varphi/(2\pi - 2\Theta)$$

and decreases in a nearly linear way for increasing angle Θ.

- Small foundation angles ($\Theta < 25°$) offer little reduction of the maximum bending moment.
- The upper half of the nozzle is loaded much more in bending than the lower half.
- The upper left quadrant of the nozzle has the highest bending moments, regardless of angle Θ.

There are always 3 points along the ring at which $BM(\varphi) = 0$.

Shear Force Distribution

- The maximum positive shear force does not occur at the point of load application.
- The maximum negative shear force is much larger than the maximum positive shear force.
- The absolute maximum of the shear force amplitude increases with increasing foundation angle.
- There exists one point along the ring where shear force is equal to zero.
- The left half of the nozzle is loaded more in shear than the right half.

Tangential Force Distribution (Force tangential to the arc of the ring)

- The absolute maximum occurs always at the support nearer the load application.
- It decreases with the growth of the foundation angle Θ.
- The left side of the nozzle ring is more loaded in tangential force than the right side.

- Left upper quarter of the ring is compressed.

Deflections Along the Ring (Normal)

- The maximum normal deflections occur near (but not at) the point of load application.
- Deflections decrease nearly linearly with increasing angle Θ.
- Deflections into the ring (positive) are of the same order of magnitude as those out of the ring (negative).

Summaries of the maximum positive and negative values found along the ring are given in Table 8.4.

8.4.a BM SUMMARY

$\theta°$	$-(C_{BM})_{max}$	$+(C_{BM})_{max}$	$(C_{BM})_{total}$	$(C_{BM})_{average}$
0	-.591	+.409	1.000	.201
15	-.556	+.333	.889	.171
30	-.498	+.256	.742	.137
45	-.418	+.164	.582	.101
60	-.324	+.128	.414	.066
75	-.204	+.045	.230	.028
90	-.000	.000	.000	.000

8.4.b SHEAR FORCE SUMMARY

$\theta°$	$(-C_{SF})_{max}$	$(+C_{SF})_{max}$
0	- .765	.296
15	- .783	.273
30	- .805	.235
45	- .836	.186
60	- .891	.318
75	- .960	.043
90	-1.00	.0

8.4.c TANGENTIAL FORCE SUMMARY

$\theta°$	$(C_{TF})_{max}$	$(+C_{TF})_{max}$
0	-.75	+.25
15	-.706	+.183
30	-.631	+.124
45	-.529	+.088
60	-.402	+.050
75	-.234	+.015
90	0	0

8.4.d DEFLECTIONS ALONG THE RING (NORMAL) SUMMARY

$\theta°$	$(+C_{\delta N})_{max}$	$(-C_{\delta N})_{max}$
0	.352	-.313
15	.236	-.208
30	.144	-.121
45	.075	-.063
60	.031	-.028
75	.009	-.004
90	0	0

TITLE:
SIDE IMPACT ($\alpha = 90^{\circ}$) MAXIMUM
VALUE SUMMARY

TABLE 8.4

Stresses and deformations for each particular nozzle are calculated below using the following notations:

$\sigma_{BM}/F = C_{BM}R/Z$ stress due to bending per unit load applied.

$\sigma_{TF}/F = C_{TF}/A_{tot}$ stress due to tangential force per unit load applied.

$\tau/F = C_{SF}/A_{Shear}$ stress due to vertical shear force per unit load applied.

$\delta_{N/F} = C_{\delta n}\ R^3/EI$ normal deflection per unit load applied.

For the sake of illustration, the computed values for some of the nozzles are given in the following table:

$\Theta = 15°$

NOZZLE	σ_{BM}/F	σ_{TF}/F	τ/F*	δ_N/F
1A	-.0107	-.0010	-.0017	$2.6\ 10^{-7}$
1B	-.0080	-.0009	-.0013	$1.6\ 10^{-7}$
1C	-.0063	-.0007	-.0011	$1.2\ 10^{-7}$
2A	-.0054	-.0005	-.00086	$2.6\ 10^{-7}$
2B	-.0040	-.0004	-.00070	$1.6\ 10^{-7}$
2C	-.0031	-.0004	-.00060	$1.2\ 10^{-7}$

*Not at a foundation point.

Where:

$(C_{BM}) = -.556$
$(C_{TF}) = -.706$
$(C_{SF}) = -.343$
$(C_{\delta N})_{max} = .236$

Based on the above values, the governing stresses and deformations are established as follows:

1. Examination of the table shows that the stresses due to bending are much higher than the stresses caused by either shear or hoop forces.

   Therefore it is not important to search for the maximum combined stress due to compressive (tensile) bending stress and shear stress.

2. Bending stress must be corrected for the non-linear distribution, i.e. (see section 8.3)

   $\sigma_{BMi} = \sigma_{BM} \times k_{in}$ where k_{in} - inside fibre stress multiplier, and

   $\sigma_{BMo} = \sigma_{BM} \times k_{out}$ where k_{out} - outside fibre stress multiplier.

3. To those bending stresses, the hoop stress must be added. Results of the calculations are given below; where i and o denote inner and outer fibre, respectively:

NOZZLE	$(\sigma_{BM}/F)_i$	$(\sigma_{BM}/F)_o$	σ_{tot}/F_i	$(\sigma_{tot}/F)_o$
1A	-.0111	+.0104	-.0121	0.0094
1B	-.0083	+.0077	-.0092	0.0068
1C	-.0066	+.0050	-.0073	0.0043
2A	-.0055	+.0053	-.0060	0.0048
2B	-.0041	+.0039	-.0045	0.0035
2C	-.0032	+.003	-.0036	0.0026

Thus we conclude, after examining the table, that material will reach yield on the inner surface of the ring first (in compression).

The outer plating stress (tension) is approximately 20% lower then the inner plate stress.

4. A shear stress check was done by inspection. Noting the strength of material in shear is approximately 1/2 of that in yield, and further noting, that the shape factor for the maximum shear force location is 1 (if shear area is that of the web only), we concluded that

   $$\tau/F \ll \sigma_{BM}/F,$$

   (a factor of 3 at the foundation). Consequently shear is not an important consideration in the nozzles under investigation.

   Note that if the force is not uniformly distributed along the nozzle's length, shear may become a locally important consideration.

5. Calculations of the minimum force causing yield were made based on the equation (see page 84):

   $$\sigma_{BM} = F.R.C_{BM}/Z = \sigma_y$$

   $\sigma_y = 3.610^4 N/m^2$ from which we get:

   $$F = \sigma_y/(\sigma_{totBM}/F)$$

6. Calculations of the minimum force resulting in a 0.005R deformation were done using the equation (see page 84):

   $0.005R = (\delta_N/F).F$, and

   $$F = 0.005R/(\delta_N/F)$$

For a 1% tip clearance values twice those obtained from the above are used.

Canmar's recent icebreakers have 1% of the radius as a tip clearance.

Tabulation of the minimum force based on the yielding of material and deformations reaching 0.5% and 1.0% of the nozzles radius is given below:

NOZZLE	FORCE [MN] MOMENT-WISE	FORCE [MN] .5% DEFLECTION-WISE	FORCE [MN] 1% DEFLECTION-WISE
1A	3.0	2.1	4.2
1B	3.9	3.5	7.0
1C	4.9	4.8	9.6
2A	6.0	4.2	8.4
2B	8.0	7.0	14.0
2C	10.0	9.6	19.2

Thus we can conclude that the yielding due to bending is the limit of maximum radial force applied to the nozzle. Variation of the strength of the nozzle series (expressed in MN) with diameter is shown on Figure 8.6.

8.6 Detailed Analysis Of Bottom Impact

Bending moment is $M(\varphi) = M_A - FR/2 \sin\varphi + H_A R (1-\cos\varphi)$. See Figure 8.3 for definitions.

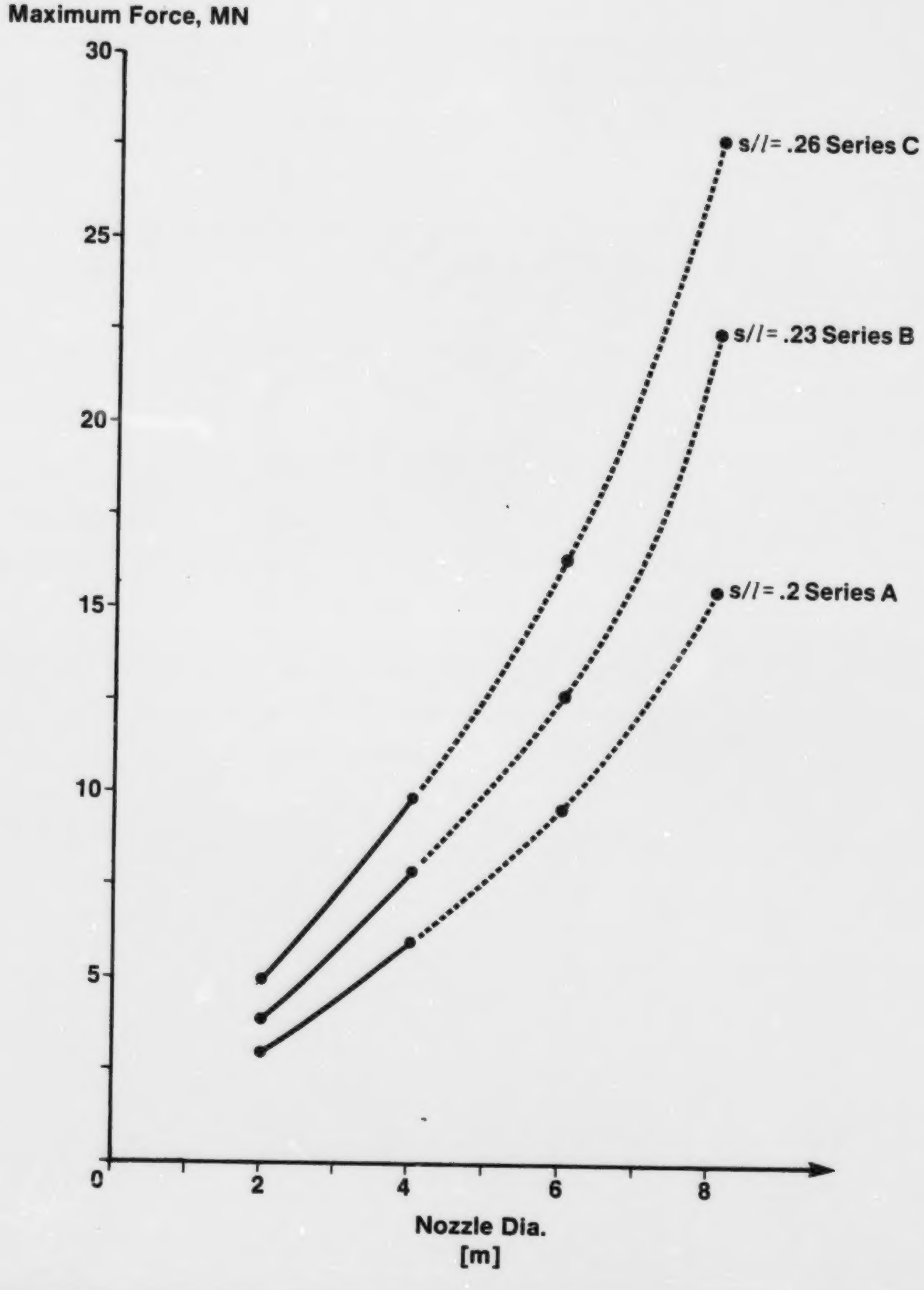
$$\partial M/\partial M_A = 1$$
$$\partial M/\partial H_A = (1 - \cos\varphi)$$

Using Castigliano's theorem, we arrive at the following equations

$$M_A(\pi - \Theta) + H_A R(\pi-\Theta-\sin\Theta) = FR\ ((1 + \cos\Theta)/2)$$

$$M_A(\pi-\Theta-\sin\Theta) + H_A R(3(\pi-\Theta)/2 - 2\sin\Theta - 1/4\sin 2\Theta) = FR(3+4\cos\Theta+\cos 2\Theta)/8$$

The solution of which, expressed as coefficients at point A are:



CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Limiting Impact Force For The Side Impact Scenario FIGURE No. 8.6

C_{TF} = $(1+\cos\theta/(\pi-\theta) - (\sin\theta)/2) / ((\pi-\theta)/\sin\theta - 2\sin\theta/(\pi-\theta)-\cos\theta)$

C_{BM} = $((1+\cos\theta)/2 - (\pi-\theta-\sin\theta)\ H_A/F)/\ (\pi-\theta)$

The values of the coefficients at points A and O (the foundation) are:

$\theta°$	$(C_{TF})_A$	$(C_{BM})_A$	$(C_{BM})_O$
0	0	.318	-.318
15	.055	.291	-.270
30	.116	.262	-.228
45	.183	.234	-.193
60	.259	.206	-.161
75	.349	.178	-.134
90	.459	.151	-.110

The total foundation reactions are given in the following table:

$\theta°$	R_L	R_R	R_{tot}	$(C_{BM})_L$	$(C_{BM})_R$	$(C_{BM})_{tot}$
0	.500	.500	1	-.318	.318	0
15	.503	.503	1	-.270	.270	0
30	.313	.513	1	-.228	.228	0
45	.532	.532	1	-.193	.193	0
60	.563	.563	1	-.161	.161	0
75	.610	.610	1	-.134	.134	0
90	.678	.678	1	-.110	.110	0

Where the subscripts L and R denote left and right foundations and R denotes a nondimensional reaction force (R/F).

The following observations can be made regarding the reactions:

- Increase of Θ leads to a decrease in the reaction bending moment at both ends of the foundations.
- The bending moment is symmetrically distributed.
- The magnitude of the reaction force increases with increasing foundation angle Θ.
- The reaction force is symmetrically distributed about the vertical axis of the ring.

Bending moments, shear forces, tangential forces and deformation distributions along the ring are tabulated in Table 8.5. Figure 8.7 depicts the distributions of bending moment for $\Theta = 0°$ and 90°. Figure 8.8 shows the distribution of the deflections for $\Theta = 0°$.

The following points are worth noting:

Bending Moment Distribution

- The maximum bending moment occurs at the foundation.
- The minimum bending moment occurs approximately half way between the foundation and the point of load application.
- An increase of the foundation angle Θ leads to a decrease of bending moment.
- The minimum bending moment is approximately 1/2 of the maximum (absolute values).

Shear Force Distribution

- The maximum shear force occurs at the foundation.
- Due to the symmetry, shear force is 0 at the point of load application.
- The shear force varies slightly with change of the foundation angle Θ.

φ° θ	0	15	30	45	60	75	90	105	120	135	150	165	180
0	.318	.188	.068	-.035	-.115	-.165	-.182	-.165	-.115	-.035	+.068	.188	.318
15	.270	.144	.031	-.059	-.123	-.154	-.151	-.114	-.046	.048	.163	.291	-
30	.228	.106	.003	-.075	-.122	-.135	-.113	-.057	.027	.136	.262	-	-
45	.193	.075	-.018	-.083	-.113	-.107	-.066	.008	.111	.234	-	-	-
60	.161	.049	-.035	-.085	-.097	-.071	-.009	.085	.206	-	-	-	-
75	.134	.027	-.046	-.080	-.073	-.025	.060	.178	-	-	-	-	-
90	.110	.008	-.052	-.068	-.037	+.037	.151	-	-	-	-	-	-

SHEAR FORCE DISTRIBUTION

C_{SF}

φ° θ	0	15	30	45	60	75	90	105	120	135	150	165	180
0	+.500	+.483	+.433	+.353	+.25	+.129	0	-.129	-.25	-.353	-.433	-.483	-.500
15	+.497	+.460	+.392	+.297	+.182	+.055	-.076	-.202	-.315	-.405	-.469	-.500	-
30	+.491	+.435	+.350	+.241	+.116	-.017	-.149	-.271	-.375	.453	-.500	-	-
45	+.483	+.408	+.306	+.183	+.047	-.091	-.224	-.341	-.435	-.500	-	-	-
60	+.474	+.379	+.259	+.121	-.026	-.170	-.303	-.416	-.500	-	-	-	-
75	+.466	+.349	+.208	+.052	-.107	-.258	-.393	-.500	-	-	-	-	-
90	+.459	+.314	+.147	-.029	-.203	-.364	-.500	-	-	-	-	-	-

TANGENTIAL FORCE DISTRIBUTION

C_{TF}

φ° θ	0	15	30	45	60	75	90	105	120	135	150	165	180
0	0	-.129	-.250	-.353	-.433	-.483	-.500	-.483	-.433	-.353	-.250	-.129	0
15	-.076	-.202	-.315	-.405	-.470	-.500	-.497	-.460	-.392	-.298	-.182	-.055	-
30	-.150	-.271	-.375	-.453	-.500	-.513	-.491	-.435	-.350	-.241	-.116	-	-
45	-.224	-.341	-.435	-.500	-.530	-.524	-.483	-.408	-.306	-.183	-	-	-
60	-.303	-.416	-.500	-.55	-.562	-.537	-.474	-.379	-.259	-	-	-	-
75	-.392	-.500	-.573	-.607	-.600	-.552	-.466	-.349	-	-	-	-	-
90	-.500	-.602	-.662	-.678	-.647	-.573	-.459	-	-	-	-	-	-

CANADIAN MARINE DRILLING LIMITED

STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE:
BENDING BOTTOM IMPACT MOMENT DISTRIBUTION C_{BM}

TABLE 8.5

NORMAL DEFLECTION DISTRIBUTION

$C_{\delta N}$

φ° / θ	0	15	30	45	60	75	90	105	120	135	150	165	180
0	0	-.009	-.031	-.055	-.073	-.079	-.068	-.040	+.001	.050	.098	.135	.149
15	0	-.008	-.025	-.042	-.053	-.052	-.038	-.010	.025	.062	.092	.104	-
30	0	-.006	-.019	-.032	-.037	-.031	-.014	+.010	.039	.062	.072	-	-
45	0	-.005	-.015	-.023	-.024	-.016	.004	.0211	.040	.048	-	-	-
60	0	-.004	-.011	-.015	-.013	-.004	.011	.025	.032	-	-	-	-
75	0	-.003	-.008	-.010	-.005	.004	.015	.020	-	-	-	-	-
90	0	-.002	-.005	-.005	.0003	.008	.012	-	-	-	-	-	-

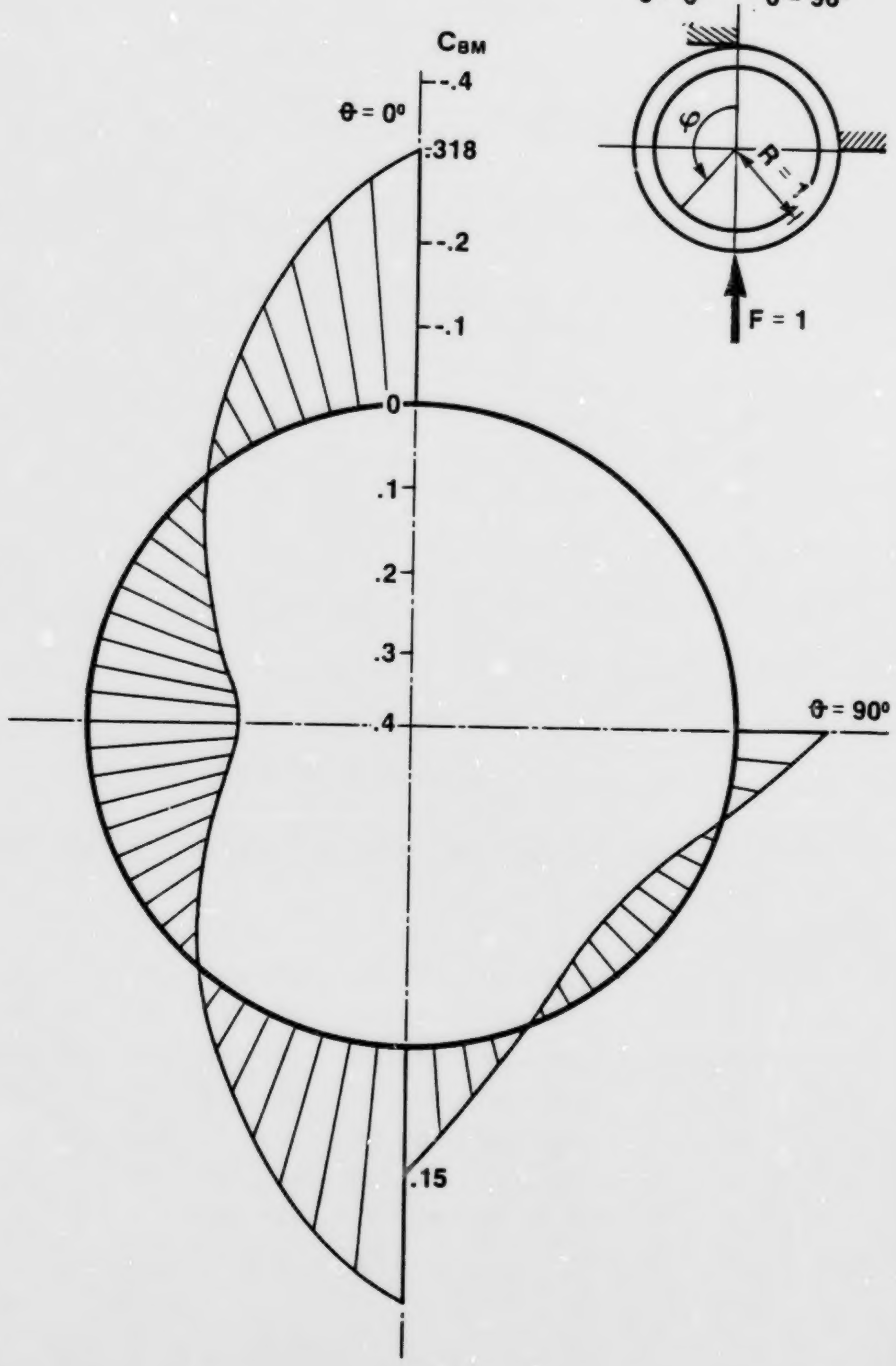
TANGENTIAL DEFLECTION DISTRIBUTION

$C_{\delta T}$

φ° / θ	0	15	30	45	60	75	90	105	120	135	150	165	180
0	0	-.0008	-.006	-.017	-.034	-.055	-.074	-.089	-.094	-.087	-.068	-.037	0
15	0	-.0007	-.005	-.014	-.026	-.041	-.053	-.035	-.057	-.040	-.021	-.000	-
30	0	-.0006	-.004	-.011	-.020	-.029	-.035	-.036	-.030	-.016	+.000	-	-
45	0	-.0005	-.003	-.008	-.015	-.020	-.022	-.019	-.011	+.000	-	-	-
60	0	-.0004	-.002	-.006	-.010	-.012	-.012	-.007	.000	-	-	-	-
75	0	-.0003	-.002	-.004	-.0065	-.007	-.004	-.001	-	-	-	-	-
90	0	-.0002	-.001	-.003	-.0034	-.0024	.000	-	-	-	-	-	-

TITLE:

TABLE 8.5 (CONT'D)



CANADIAN
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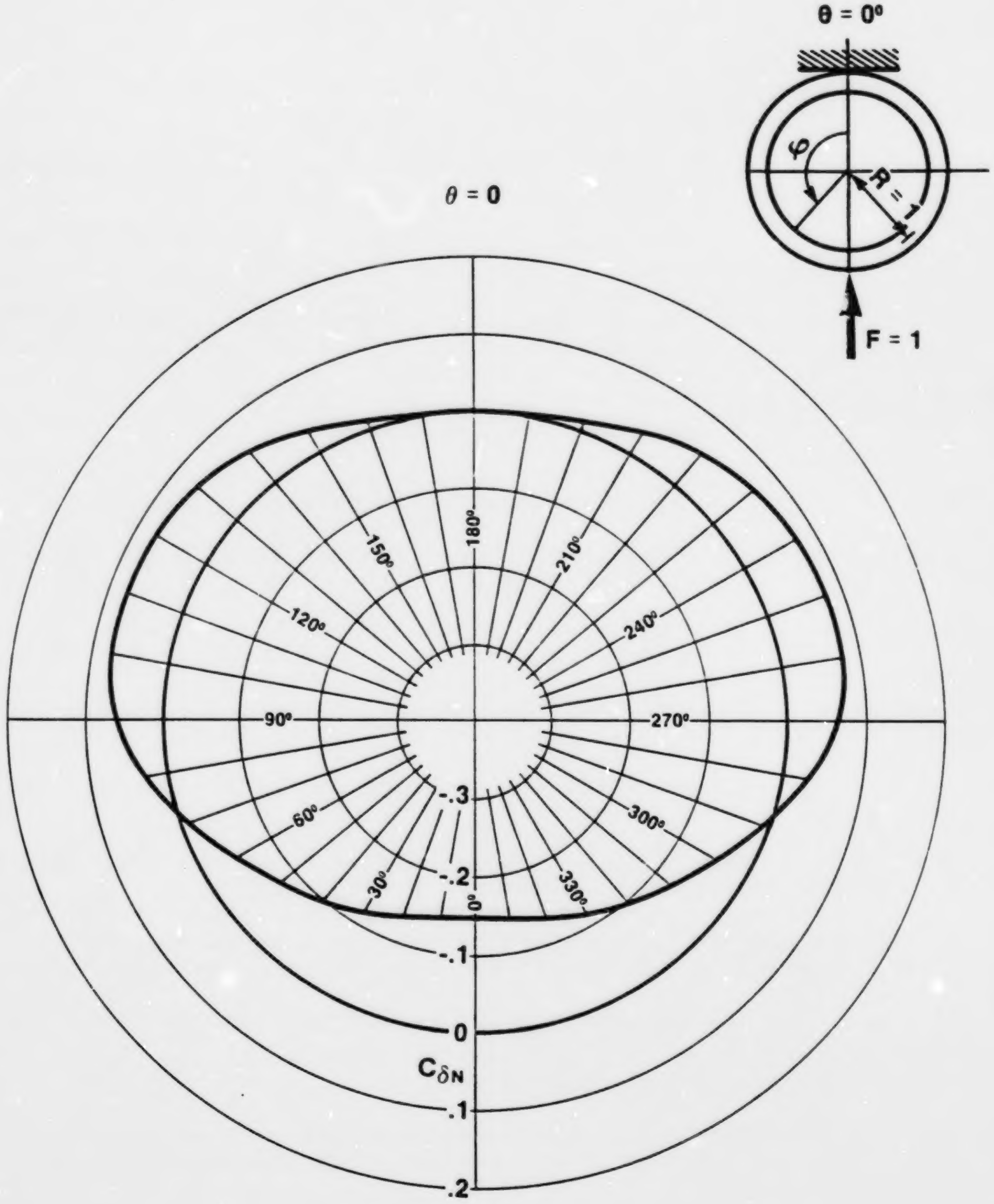
LIMITED

Strength Requirements
For Nozzles For Ice
Transitting Ships

Bending Moment Distribution For Bottom Impact

FIGURE No. 8.7



CANADIAN MARINE DRILLING LIMITED

Strength Requirements For Nozzles For Ice Transitting Ships

TITLE: **Deflection Distribution For Bottom Impact**

FIGURE No. 8.8

Tangential Force Distribution

- This force is always negative, which shows that the whole ring is in compression.
- An increase of Θ leads to an increase of the absolute magnitude of the force.
- The minimum occurs approximately half way between the point of the application of the load and the foundation.

Normal Deflection Distribution

- The largest inwards deflections occur at the point of application of the load.
- Deflections rapidly decrease with the increase of the angle Θ.
- The largest outward deflections are approximately half of the inward deflections.

Summaries of the extreme values are given in Table 8.6.

Stresses and deformations for each particular nozzle are given in Table 8.7.

Examination of these values shows that, as it was the case for the side impact, the shear stress and hoop stresses are of an order of magnitude lower then those due to bending. Therefore maximum bending stresses will govern the search for the limiting stress case.

The maximum C_{BM} occurs at the point of load application, however, the difference between that and the value at foundation is not great.

Stresses and deformations for each of the nozzles are calculated using the procedure developed for the side impact.

For the $\Theta = 15°$, the computed stresses are given in the following table.

Calculations were done for the maximum force allowed taking into account bending and tangential stress, bending being corrected for the curvature effect (stress multipliers k_{in}, k_{out}).

NOZZLE	$(\sigma_{BM}/F)_i$	$(\sigma_{TF}/F)_o$	$(\sigma_{tot}/F)_i$	$(\sigma_{tot}/F)_o$
1A	0.0054	0.0050	.0055	.0051
1B	0.0040	0.0037	.0041	.0038
1C	0.0032	0.0029	.0033	.0030
2A	0.0027	0.0025	.0028	.0025
2B	0.0020	0.0018	.0020	.0018
2C	0.0016	0.0014	.0016	.0014

Calculations of the maximum force the nozzle ring can withstand is done using the formula.

$$F = (3.610^4 N/cm^2)/(\sigma_{tot}/F)_i$$

For the 0.5%, (see section 8.5) the allowable deflection is:

$$F = 0.005R/(\delta_N/F)$$

Results are tabulated below.

NOZZLE	FORCE [MN] MOMENT-WISE [MN]	FORCE [MN] .5% DEFLECTION-WISE	FORCE [MN] 1% DEFLECTION-WISE
1A	6.5	4.82	9.69
1B	8.8	8.0	16.00
1C	10.9	10.9	21.83
2A	12.8	9.6	19.2
2B	18.0	16.0	32.0
2C	22.5	21.7	43.4

θ°	$(+C_{BM})_{max}$	$(-C_{BM})_{max}$	$(C_{BM})^{*}_{total}$
0	.318	-.182	0
15	.291	-.154	0
30	.262	-.135	0
45	.234	-.113	0
60	.206	-.097	0
75	.178	-.068	0

*Total BM acting on the foundation

SHEAR FORCE SUMMARY

θ°	$(-C_{SF})_{max}$	$(+C_{SF})_{max}$
0	-.500	+.500
15	-.500	+.497
30	-.500	+.491
45	-.500	+.483
60	-.500	+.474
75	-.500	+.466
90	-.500	+.459

CANADIAN MARINE DRILLING LIMITED

STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE: BOTTOM IMPACT (α = 180°)
MAXIMUM VALUE SUMMARY
BM SUMMARY

TABLE 8.6

TANGENTIAL FORCE SUMMARY

$\theta°$	$(+C_{TF})_{max}$	$(-C_{TF})_{max}$
0	0	-.500
15	-	-.500
30	-	-.500
45	-	-.500
60	-	-.500
75	-	-.500
90	-	-.500

DEFLECTIONS ALONG THE RING SUMMARY

$\theta°$	$(C_{\delta N})_{max}$	$(C_{\delta T})_{max}$
0	.149	-.094
15	.104	-.059
30	.072	-.036
45	.048	-.022
60	.032	-.012
75	.020	-.007
90	.012	-.0035

CANADIAN
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LIMITED

STRENGTH REQUIREMENTS FOR
NOZZLES FOR ICE
TRANSITING SHIPS

TITLE:
BOTTOM IMPACT (α = 180°)
MAXIMUM VALVE SUMMARY

TABLE 8.6.C

NOZZLE	σ_{BM}/F	σ_{TF}/F	σ_{SF}/F	δ_N/F $\times 10^7$
1A	0.0052	0.00011	.00082	1.14
1B	0.0039	0.00010	.00063	.705
1C	0.0031	0.00007	.00053	.529
2A	0.0026	0.00005	.00042	1.14
2B	0.0019	0.00004	.00034	.705
2C	0.0015	0.00004	.00029	.529

Where:

C_{BM} = .270

C_{SF} = .497 (At the foundation)

C_{TF} = −.076

$C\delta_N$ = .104

1A	0.0056	.00008	.00083	1.14
1B	0.0042	.00007	.00063	.705
1C	0.0033	.00005	.00053	.529
2A	0.0028	.000036	.00042	1.14
2B	0.0020	.000029	.00034	.705
2C	0.0016	.000029	.00029	.529

Where:

C_{BM} = .291

C_{SF} = −.500 (At the point of load application)

C_{TF} = −.055

$C_{\delta N}$ = .104

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STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE: NON-DIMENSIONAL STRESS AND DEFORMATIONS FOR EXAMPLES FROM NOZZLE SERIES

TABLE 8.7

8.7 Generalization Of the Point Of The Load Application

The two previously studied cases, ie the bottom and side impacts, may not have been the highest stress cases. A computer programme was developed for the purpose of establishing the influence of the location of the radial force on the magnitude of bending moment. Table 8.8 shows the magnitudes of maximum (minimum) bending moments and their locations as a function of the foundation angle Θ and the direction of the point load application. The maximums of maximum bending moments $((C_{BM})\text{max})\text{max}$ as a function of the angle Θ are plotted in Figure 8.9.

From this figure, it is evident that the maximum of maximum bending moments decreases linearly with Θ.

We can write this relationship as follows:

$$((C_{BM})\text{max})\text{max} \cong .645 - \Theta°/213$$

This function enables us to calculate the maximum of maximum bending moment coefficients for any angle Θ.

The point of the application of the radial load which produces the maximum of maximum bending moments moves away from the foundation as shown below:

Angle $\Theta°$	Angular Distance Between Foundation and Load Application
75°	35°
60°	40°
45°	50°
30°	55°
15°	60°
0°	75°

If we idealized the segment of the nozzle ring between the support nearer to the point of load application and the point of load application as a cantilever beam, then the maximum bending moment would be:

$$BM = F \times R \times (C_{BM})_{cant} = F \times R \times \sin(180° - \Theta° - \varphi)$$

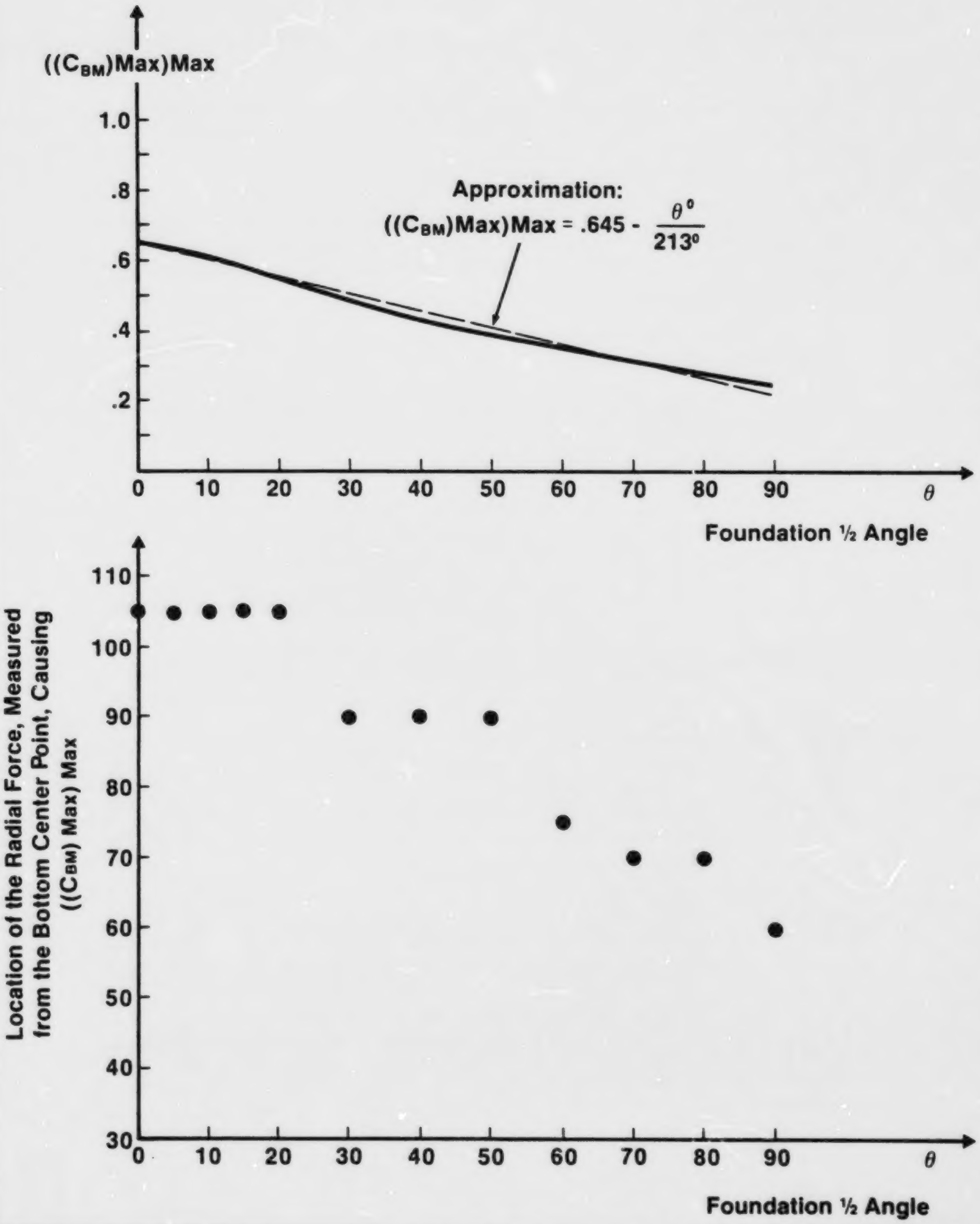
Comparing these values with the actual $((C_{BM})_{max})_{max}$ we can conclude that the remaining part of the nozzle ie from the point of load application to the foundation farther from the point of load application, provides a very significant support which

						C_{BM}						
θ	0°	5°	10°	15°	20°	30°	40°	50°	60°	70°	80°	90°
((CBM)MAX)MAX	.647	.627	.603	.577	.547	.496	.447	.392	.354	.314	.273	.241
Location of ((CBM)MAX)MAX	0	5°	10°	15°	20°	30°	40°	50°	60°	70°	80°	90°
Location of Force Causing ((CBM)MAX)MAX	105°	105°	105°	105°	105°	90°	90°	90°	75°	70°	70°	60°
						C_{SF}						
(CSF)MAX	.842	.853	.859	.864	.878	.803	.829	.856	.773	.763	.823	.778
Location of (CSF)MAX	60°	60°	60°	60°	65°	75°	85°	80°	105°	110°	110°	120°
						C_{TF}						
(CTF)MAX	.765	.780	.711	.679	.640	.630	.567	.493	.509	.478	.403	.417
Location of (CTF)MAX	0	0	0	0	0	0	0	0	0	0	0	0

NOTE: VALUES OF (CSF)MAX AND (CTF)MAX ARE GIVEN FOR THE LOCATION OF FORCE CAUSING ((CBM)MAX)MAX

TITLE: THE MAXIMUM VALUES OF BENDING MOMENT' SHEAR FORCE AND TANGENTIAL FORCE COEFFICIENTS AS A FUNCTION OF THE FOUNDATION ANGLE

TABLE 8.8



CANADIAN MARINE DRILLING LIMITED

Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: Variation Of The Maximum Of Maximum Bending Moment Coefficient With The Foundation Angle θ

FIGURE No. 8.9

reduces the $(C_{BM})_{cant}$ value by the percentages shown below:

$\Theta°$	$((C_{BM})_{max}/(C_{BM})_{cant}$
0°	65%
90°	48%

From the table it is evident that the maximum of maximum bending moment coefficients is 0.577 (for $\Theta = 15°$). This value will be used for the assessment of nozzle strength.

Some important observations can be made after examining the Table 8.8:

1. Maximum of maximum bending moment coefficients occurs always at the foundation near the force application point.

2. There is a factor of 2.68 between $((C_{BM})_{max})$max for angle $\Theta = 0°$ and $\Theta = 90°$.

   Thus increasing the foundation angle is an effective way of decreasing the bending moment.

3. Side impacts produce the maximum bending moments. For moderate angles Θ, the point of load application varies between 90° and 105°.

4. Maximum shear force coefficients vary between .773 and .878 which is within 13% only.

5. The tangential force coefficient decreases with the increase of the angle Θ. (C_{TF})max occur always at the foundation.

6. Side impacts give approximately twice the maximum bending moment coefficients than for bottom impacts. (Compare table 8.6 with 8.7.)

Appendix A gives examples of bending moment, shear force and tangential force coefficients for various load application points. Detailed distributions are given for those points which produce the maximum bending moment coefficients. For $\Theta = 15°$ and a point load located at

$\varphi = -105°$, tabulation of C_{BM}, C_{SF} and C_{TF} is given below.

ANGLE * DEG	C_{BM}	C_{SF}	C_{TF}
-165	-.517	-.543	-.679
-150	-.413	-.700	-.515
-135	-.214	-.810	-.316
-120	.006	-.864	-.096
-105	.233	-.859	.131
-90	.192	.170	.090
-75	.145	.187	.043
-60	-.045	.192	-.007
-45	.046	.184	-.056
-30	0.000	.163	-.102
-15	-.039	.131	-.141
0	-.068	.090	-.170
15	-.085	.043	-.187
30	-.090	-.007	-.192
45	-.082	-.056	-.184
60	-.061	-.102	-.163
75	-.029	-.141	-.131
90	.012	.170	-.090
105	.059	-.187	-.043
120	.109	-.192	.007
135	.158	-.184	.056
150	.204	-.163	.102
165	.243	-.131	.141

* Measured Clockwise from the Bottom Centre Point

8.8 Generalization Of The Point Load Into Distributed Load

In order to find out the influence of the distribution of the load on the maximum magnitude of bending moment, a computer subroutine was developed. A unit load was spread at 5° intervals as follows:

Total Load	Composite Loads	Angular Area Covered "Spread Angle"
1	1 x 1	0°
1	3 x 1/3	15°
1	5 x 1/5	25°

Table 8.9 summarizes the positions and magnitudes of maximum bending moment coefficients as a function of nozzle foundation angle and "spread angle".

The following points are worth noting:

- There are significant reductions of the maximum bending moment coefficients due to load spreading.
- The degree of reduction depends on the location of the load and the nozzle's foundation angle. As expected, the smaller the foundation angle Θ, the less effective load spreading is in reducing the coefficients' value.

From Table 8.9 we can conclude that for the practical range of nozzle foundation angles (< 30°) load spreading has small (< 2%) effect on the magnitude of the maximum bending moment coefficient.

8.9 Axial Loading On The Nozzle

In addition to the bending moments, axial loading generates torsional loads which must be accounted for in the computations of stresses. Figure 8.10 shows the load geometry and notations used.

The use of Castigliano theorem is required in this case since the problem is statically indeterminate.

Values of the torsional rigidity β are given in Table 8.10. Since the torsional rigidity of the ring is high ($\beta >> 10$), it is clear that the ring will carry a large part of its load in torsion.

8.9.1 Bottom Impact

This is the symmetrical load case, and the expression for bending moment is:

$$M(\varphi) = -(M\cos\varphi + FR/2 \sin\varphi)$$

The expression for torsional moment $Q(\varphi)$ is:

$$Q(\varphi) = M\sin\varphi + FR/2(1-\cos\varphi)$$

where M is the bending moment at the point of application of load.

This moment is calculated as follows:

$$C_{BM} = ((\cos 2\Theta - 1)/EI - (3 + 4\cos\Theta + \cos 2\Theta)/c) / (4(\pi - \Theta)(1/c + 1/EI) + 2(1/c-1/EI)\sin 2\Theta)$$

INPUTS: Unit load is spread at 5° intervals, e.g. load spread 3, acting at 60° means 3 concentrated loads of .333 spaced at 55°, 60° and 65°.

Maximum Bending Moment Coefficients and Angular Position x*

NOZZLE FOUNDATION ANGLE Θ = 60°

Centre of Load Application

LOAD SPREAD	0°	x	5°	x	30°	x	60°	x	90°	x
1	.206	0°	.207	5°	.281	-120°	-.307	120°	-.328	120°
3	.178	0°	.192	-120°	.279	-120°	-.305	120°	-.324	120°
5	.158	-120°	.189	-120°	.276	-120°	-.301	120°	-.318	120°

NOZZLE FOUNDATION ANGLE Θ = 45°

LOAD SPREAD	0°	x	5°	x	30°	x	60°	x	90°	x
1	.234	0°	.234	5°	.334	-135°	-.328	135°	-.421	135°
3	.206	0°	.226	-135°	.332	-135°	-.326	135°	-.418	135°
5	.190	135°	.224	-135°	.329	-135°	-.323	135°	-.413	135°

* x Denotes the location of maximum bending moment coefficient, measured from the vertical axis of symmetry (see Appendix A).

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TITLE: MAXIMUM BENDING MOMENT COEFFICIENTS CAUSED BY DISTRIBUTED LOADS VERSUS CONCENTRATED LOAD

TABLE 8.9

NOZZLE FOUNDATION ANGLE Θ = 30°

LOAD SPREAD	0°	x	5°	x	30°	x	60°	x	90°	x	120	x
1	.263	0°	.267	-150°	.391	-150°	.385	-150°	-.496	150°	-.393	150°
3	.234	0°	.265	-150°	.389	-150°	.383	-150°	-.493	150°	-.390	150°
5	.226	150°	.263	-150°	.386	-150°	.381	-150°	-.488	150°	-.385	150°

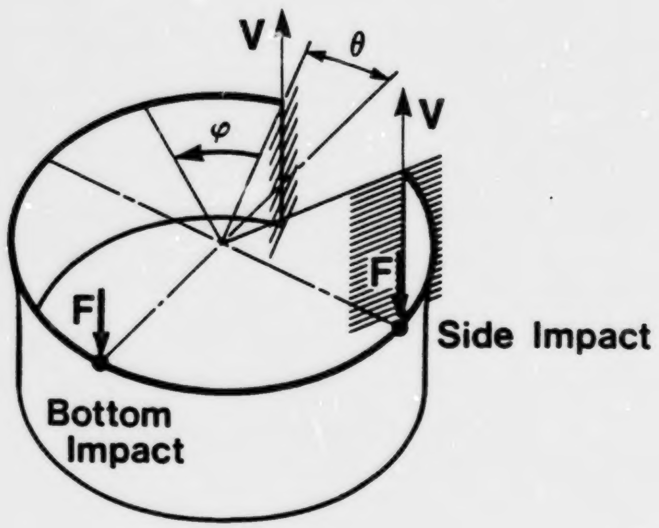
NOZZLE FOUNDATION ANGLE Θ = 15°

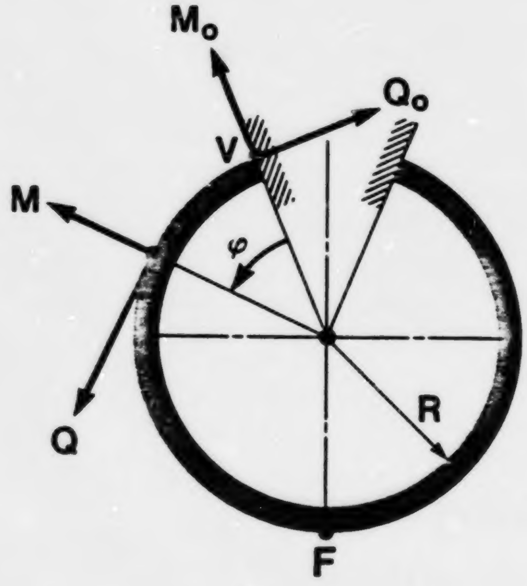
LOAD SPREAD	0°	x	5°	x	30°	x	60°	x	90°	x	120°	x	150°	x
1	.291	0°	.311	-165°	.450	-165°	.462	-165°	-.555	165°	-.532	165°	-.238	165°
3	.269	165°	.309	-165°	.448	-165°	.460	-165°	-.552	165°	-.529	165°	-.235	165°
5	.267	165°	.307	-165°	.445	-165°	.458	-165°	-.549	165°	-.524	165°	-.231	165°

MAXIMUM BENDING MOMENT AND ANGULAR POSITION

NOZZLE FOUNDATION ANGLE Θ = 5°

LOAD SPREAD	0°	x	5°	x	30°	x	60°	x	90°	x	120°	x	150°	x
1	.309	0°	.343	-175°	.488	-175°	.507	-175°	-.582	175°	-.609	175°	-.374	175°
3	.300	±175°	.342	-175°	.486	-175°	.506	-175°	-.580	175°	-.606	175°	-.372	175°
5	.298	±175°	.339	-175°	.483	-175°	.503	-175°	-.576	175°	-.602	175°	-.368	175°


V
θ
V
φ
F
F
Side Impact
Bottom Impact


M_o
Q_o
V
M
φ
Q
R
F

M – Bending moment at φ
M_o – Bending moment at the support
Q – Torsional moment at φ
Q_o – Torsional moment at the support
F – Applied load
V – Vertical reaction force

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Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: **Axial Load Geometry**

FIGURE No. 8.10

NOZZLE	INERTIA X-X cm^4	INERTIA Y-Y cm^4	Q_{x-x} cm^3_1	Q_{y-y} cm^3_2	K cm^4_3	β 4
1A	56666	750000	8531	8531	90357	21.5
1B	97395	1010880	11868	11868	152180	17.2
1C	153000	1323173	15606	15606	233056	14.7
2A	453333	6000000	37031	37031	854266	18.2
2B	773166	8087040	50706	50706	13967211	15.0
2C	1224000	10505386	65981	65981	2098687	13.1
3A	2203200	29160000	120262	120262	4178714	18.1
3B	3786750	39303014	164711	164711	6827037	14.9
3C	5948640	51444979	214244	214244	10247017	13.0
4A	6272000	78400000	252014	252014	10325032	14.7
4B	10822000	11108	344259	344259	16645792	16.4
4C	17055360	14108	447256	447256	24743876	14.5
KIG	1134352	18455775	78688	78688	1923877	24.9
RL	196875	2460937	20281	20281	296450	21.5
S1&2	141428	2249956	20280	13484	269773	21.6
S7	92577	1662657	9255	11569	192801	22.4
MVA	432476	11163626	41697	41697	957653	30.3

1. $Q_{x-x} = 2t_1 (a - t) (b - t_1)$ *
2. $Q_{y-y} = 2t (a - t) (b - t_1)$
3. $K = 2t\, t_1 (a-t)^2 (b - t_1)^2/(at + bt_1 - t^2 - t_1{}^2)$
4. $\beta = E/G\ I/K = 2.58\ I/K$

See Reference 8.1 for Definition of Terms

TITLE:
TORSIONAL RIGIDITY β OF THE
NOZZLE SERIES

TABLE 8.10

Where c is the torsional stiffness of the section. (c = Gk) The expression can be rewritten as

$$C_{BM} = (c/EI(\cos 2\theta-1)-(3+4\cos\theta+\cos 2\theta))/$$
$$(4(1+c/EI)(\pi-\theta)+2(1-c/EI)\sin 2\theta$$

Values of $-C_{BM}$ are given below:

θ *c/EI	0°	15°	30°	45°	60°	75°	90°
0	.637	.617	.571	.510	.445	.380	.318
.1	.579	.570	.536	.487	.431	.374	.318
1	.318	.341	.356	.362	.358	.343	.318
10	.058	.077	.120	.185	.255	.305	.318
100	.006	.020	.064	.140	.229	.296	.318
∞	.0	.0127	.057	.135	.225	.296	.318

* $c/EI = 1/\beta$

The following points are worth noting:

- Torsional stiffness "unloads" the bending moment for small values of θ only.
- For high torsional stiffness an increase of foundation angle leads to an increase of midspan BM. The opposite is true for the low torsional stiffness.
- Distribution of the bending moment along the ring for θ = 15° and c/EI = .1 and 10 is given.

$\varphi[°]$	C_{BM} for $c/EI = .1$	C_{BM} for $c/EI = 10$
0	-.571	-.077
15	-.422	.055
30	-.244	.183
45	-.050	.299
60	.147	.394
75	.355	.463
90	.500	.500
105	.631	.503
120	.718	.471
135	.757	.408
150	.744	.317
165	.681	.204

Note that for $\varphi = 90°$, C_{BM} is 0.5 and is independant of the torsional stiffness of the ring.

The maximum bending moment occurs at the support.

In general, however, the position of the maximum BM is determined as follows where $\varphi°$ is the angle at which the maximum bending moment coefficient occurs:

$$dBM/d\varphi = -\sin\varphi(M) + FR/2 \cos\varphi = 0$$

$$\tan\varphi_o = FR/2M$$

The values of φ_o are given below for c = 1.

$\theta°$	0	15	30	45	60	75	90
φ_o	40.8	41.2	43	45.7	49.2	53.2	57.3

Thus the absolute maximum can occur at

- the support, or
- the point of the application of load, or
- φ_o as tabulated above.

Table 8.11 A and B give the values of the reactions, bending moments, torque and shear in the nozzle ring for varying nozzle foundation angle, point of load application and torsional stiffness equal to 10.

For β = 10, the maximum bending moment coefficients as a function of the load application point are as follows:

Nozzle Foundation Angle, Θ Degrees	Position of Applied Load, deg.				
	60	70	80	90	100
90	-.615				
80		.689			
70		.759			
60			.830		
50				.891	
40				.949	
30				.992	
20					1.026
10					1.04623

For β = 10, the maximum twisting moment coefficients as a function of the load application point are as follows:

	80	90	100	110	120	130	140
90	.190						
80	.248						
70		.318					
60			.399				
50				.492			
40					.596		
30						.710	
20						.833	
10							.963

REACTIONS, BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

Fd	Va	Ma	Ta	Vb	Mb	Tb *
165	.500	-.681	.835	-.500	-.681	-.835

TRANSVERSE SHEAR, BENDING AND TWISTING MOMENT ALONG NOZZLE

$\beta = 10$

Coordinate (°) x*	Shear Force Coefficient C_{SF}	Bending Moment Coefficient C_{BM}	Torque Coefficient C_Q
0	.500	-.681	.835
15	.500	-.744	.648
30	.500	-.757	.450
45	.500	-.718	.256
60	.500	-.631	.078
75	.500	-.500	-.071
90	.500	-.335	-.181
105	.500	-.148	-.244
120	.500	.050	-.257
135	.500	.244	-.218
150	.500	.422	-.131
165	.500	.571	.000
180	-.500	.422	.131
195	-.500	.244	.218
210	-.500	.050	.257
225	-.500	-.148	.244
240	-.500	-.335	.181
255	-.500	-.500	.071
270	-.500	-.631	-.078
285	-.500	-.718	-.256
300	-.500	-.757	-.450
315	-.500	-.744	-.648
330	-.500	-.681	-.835

* See Appendix A for Definitions

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STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE: UNIT CONCENTRATED AXIAL LOAD CASE BOTTOM IMPACT NOZZLE FOUNDATION ANGLE (DEGREES) = 30°

TABLE 8.11.A

REACTIONS, BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

Fd	Va	Ma	Ta	Vb	Mb	Tb
255	.070	-.069	.178	-.930	-.972	-.543

TRANSVERSE SHEAR, BENDING AND TWISTING MOMENT ALONG NOZZLE

$\beta = 10$

Coordinate (°) x*	Shear Force Coefficient C_{SF}	Bending Moment Coefficient C_{BM}	Torque Coefficient C_Q
0	.070	-.069	.178
15	.070	-.095	.156
30	.070	-.114	.129
45	.070	-.125	.097
60	.070	-.128	.064
75	.070	-.122	.031
90	.070	-.107	.001
105	.070	-.086	-.024
120	.070	-.058	-.043
135	.070	.027	-.054
150	.070	.007	-.057
165	.070	.039	-.051
180	.070	.069	-.037
195	.070	.095	-.015
210	.070	.114	.012
225	.070	.125	.044
240	.070	.128	.077
255	.070	.122	.110
270	-.930	-.152	.106
285	-.930	-.414	.031
300	-.930	-.649	-.109
315	-.930	-.839	-.305
330	-.930	-.972	-.543

* x is measured from the vertical axis of symmetry

NOTE: FOR DEFINITION OF VARIABLES, SEE APPENDIX A

CANMAR **CANADIAN MARINE DRILLING LIMITED**	**STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS**	**TITLE: UNIT CONCENTRATED AXIAL LOAD CASE SIDE IMPACT NOZZLE FOUNDATION ANGLE (DEGREES) = 30°** **TABLE 8.11.B**

As expected, the magnitudes of both maximum twisting moments and bending moments increase with increasing angle $(\pi - \theta)$.

Worth noting is the fact that the magnitude of the bending moment coefficient is of the same order as for the radial load case. This suggests that the stresses due to bending are small, since the section modulus in the direction y-y are 2 to 3 times larger then those for the radial load case.

Thus the only checks needed to be performed for the axial load case are the torsion and shear stresses.

The shear stress coefficient is constant and equal to 1/2 everywhere along the nozzle ring.

In order to evaluate the stresses in the nozzle ring under the axial load, we proceeded as follows:

Firstly, we idealized the ring as a thin walled section of length ℓ and height H. We then identified two areas of the section to be checked for stresses:

- sides, and
- ends (short sides)

For the sides, the stresses are a combination of the stresses due to:

- bending moment
  $\sigma_{BM} = M/Z = C_{BM}FR/Z$
- shear force
  $\tau_{SF} = SF/A_{SF} = C_{SF}\ FR/(A_{SF}R)$
- torque
  $\sigma_T = T/Z_Q = C_T\ FR/Z_Q$

where Z_Q the section modulus for torque is given by:

$$Z_Q = 2t\ (\ell - t)\ (H - t)$$

For the forces at the end of the ring, the stresses are combinations of stresses due to:

- bending moment, defined as above, and
- torque, defined as above

In order to simplify the analysis, we assumed that the thickness of the thin-walled section is uniform, and equal to t. Further, by omitting the influence of the internal webs on the torsional strength of the nozzle, we concluded that the average torsional stress σ_T is constant and the same for the sides as well as for the ends of the ring. This simplification gives higher torsional stresses than the actual ones.

When we compare the expressions for shear and torsional stress, we conclude that the shear stresses are an order of magnitude lower than the torsional stresses, since:

$$\tau = C_{SF} \text{ x } F \text{ x } R/21 \text{ x } t \text{ x } R, \text{ and}$$

$$\sigma_t \cong C_T \text{ x } F \text{ x } R/21 \text{ x } t \text{ x } h \qquad \tau/\sigma_T \approx C_{SF}/C_T$$

h/R, $h/R << 1$

and C_{SF} is of the same order of magnitude as C_T.

Thus the shear stresses in the side walls can be omitted from further considerations. At either end of the ring, the principal stresses $\sigma_{1,2}$ due to torsion are:

$$\sigma_{1,2} = [\pm(\sigma_{BM}^2 + 4\sigma_T^2)^{1/2} + \sigma_{BM}] \text{ x } 1/2 \text{ and}$$

For the thin-walled hollow sections, σ_T is calculated as follows:

$$\sigma_T = \text{Torque}/(2t(\ell - t) \,.\, (H - t))$$

The combined stresses are:

$$\sigma_{comb} = (\sigma_{BM}^2 + 3\sigma_T^2)^{1/2} \leq \sigma_{yield}$$

8.9.2 The Influence Of The Bottom Nozzle Support On The Magnitude Of The Stresses In The Axial Load Case

Many ships equipped with stern frames have nozzles connected to the sole piece (foot). For the radial load case, where the nozzle ring deflections are perpendicular to the main axis of symmetry of the nozzle, the sole piece cannot contribute much strength to the nozzle ring. Indeed, the small section modulus of the sole piece and the potential of large hydrodynamic or ice-induced loads on a rudder may lead to the conclusion that the sole piece is a source of the transverse load rather than the support, for the nozzle ring.

For axial loads, however, the strength and the stiffness of sole piece is large and there is no reason to exclude it from the strength considerations. The difference in structural response between bottom supported and bottom unsupported nozzle ring for the case of axial load can be assessed by comparing the bending moment, shear force and torque differences between these two cases:

Axial Side Impact, $\beta = 20$

	BOTTOM UNSUPPORTED	BOTTOM SUPPORTED	RATIO
Max C_{BM}	-.773	-.468	0.60
Max C_{SF}	-.500	-.583	1.17
Max C_{TF}	.829	.135	.16

Thus a very significant reduction in the bending moment and torque is accomplished by attaching the nozzle ring to the sole piece.

The actual reduction of BM and T is dependent on the rigidity of the sole piece. The above calculations assumed perfect rigidity of the attachment.

8.10 Ice Load Carrying Ability Of The Nozzle

Having determined the stresses and deformations for any radial and axial load applied to the nozzle ring, we now can compare the maximum loads causing yield in the structure or causing exceedance of the deformation criteria and select the minimum acceptable load. This load is the maximum load allowed to be applied on the nozzle ring without causing either yield or excessive deformation.

These loads are calculated as follows:

Radial Load

For the Bending Moment and Tangential Force

$$F_{max} = \sigma_y / [K_i C_{BM} R/Z \pm C_{TF}/A_{\otimes}]$$

where (C_{BM})max is defined in section 8.7, and K_i is the stress multiplier as defined in 8.3. Note that (C_{BM}) max = $f(\Theta)$.

For the shear: $F_{max} = \tau \times A_{shear}/C_{SF}$

Axial Load

For the bending moment and torsional shear:

$$F_{max} = \sigma_y \left((C_{BM}/Z)^2 + 3(C_Q/Q_{x-x})^2 \right)^{-1/2}/R$$

Taking σ_y = 360 MPa, we will obtain the forces, in tonnes, as printed in the Table 8.12. These values are based on the coefficients obtained for the point loads, and do include the bottom support for the axial load case.

From Table 8.12 it is evident that the maximum load allowed in the radial load case is governed by the strength of the nozzle in bending, while for the axial load case it is governed by the strength of the nozzle in combined bending and torsion. It is also evident that the radial load case is more severe then the axial case by approximately a factor of two.

For the sake of comparison, the total area needed to develop the limit force is calculated for both radial and axial loads using a propriatory pressure/area curve. For the radial load case, the arc over which load is distributed varies from 5° to 18°. Such a distribution suggests the reduction of the maximum bending moment by a factor of (see section 8.8):

$$(BM_{min})\text{distrib}/(BM_{min})\text{point} = .994$$

Thus the reduction is insignificant.

For the axial load case, the load distribution arc is very large. This leads to the lowering of the bending and twisting moments and, correspondingly, to the increase of strength for that particular case. Thus the radial load strength becomes even more important.

Figure 8.11 shows the comparison between the designed nozzle series radial strengths, expressed in tonnes, as a function of nozzle diameter. In addition, the strengths of existing nozzles are calculated and plotted.

NOZZLE	YIELD STRESS KG/CM^2	RDL STRT IN SHEAR TONNES	RDL STRT TENS/COMP TONNES	RDL STRT BEND'G TONNES	AXL STRT IN SHEAR TONNES	AXL STRT BEND'G TONNES	AXL STRT TORQUE TONNES	AXL STRT BM + TM TONNES	RDL FORC AREA M^2	RDL FORC ARC DEG	AXL FORC AREA M^2	AXL FORC ARC DEG
1A	3600	-480	-3711	-310	1038	-870	1026	674	0.18	8	0.66	157
1B	3600	-601	-4188	-414	1121	-1062	1395	857	0.26	11	0.84	155
1C	3600	-721	-4665	-528	1204	-1266	1795	1048	0.35	13	1.05	155
2A	3600	-961	-7422	-625	2077	-1740	2227	1391	0.43	5	1.64	98
2B	3600	-1202	-8377	-836	2243	-2124	2981	1752	0.62	6	2.29	105
2C	3600	-1442	-9331	-1064	2409	2532	3795	2131	0.80	8	3.23	118
3A	3600	-2077	-16032	-1351	4486	-3760	4825	3009	1.15	6	8.33	221
3B	3600	-2596	-18094	-1807	4845	-4588	6456	3788	1.74	8	13	269
3C	3600	-3115	-20155	-2298	5204	-5470	8216	4607	2.65	11	16	275
4A	3600	-4039	-26721	-2162	6979	-5686	7577	4612	2.36	7	16	251
4B	3600	-5048	-30373	-2896	7537	-6923	10121	5784	4.37	11	0.23	3
4C	3600	-6058	-34025	-3696	8096	-8238	12864	7015	7.98	18	83	-771
KIG	3600	-1993	-18176	-1427	3896	-3808	5911	3221	1.24	8	8	344
R LEMEUR	3600	-1001	-9712	-1151	1557	-2485	7092	2373	0.93	19	11	330
SUP 1&2	2400	-512	-3979	-387	608	-1041	1784	916	0.24	4	0.82	85
SUPL 7	2400	-189	-2213	-231	602	-652	984	554	0.12	2	0.46	59
MV ARCTIC	2400	-622	-9470	-350	1794	-1149	1040	798	0.63	4	0.93	50

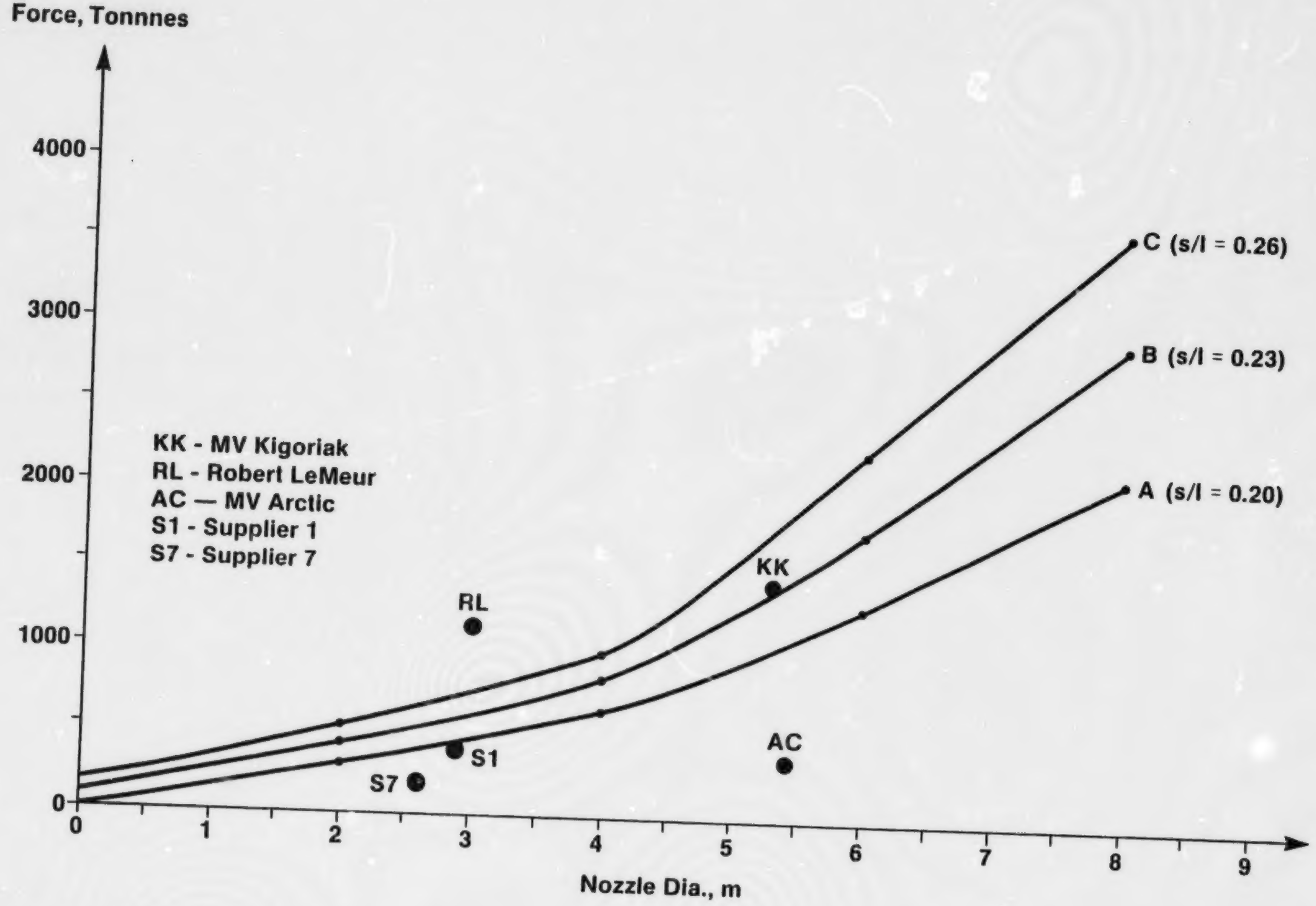
Where:
RDL = Radial
AXL = Axial
STRT = Strength
FORC = Force
TENS = Tension
COMP = Compression
BM + TM = Combined Bending and Torque

CANADIAN MARINE DRILLING LIMITED

STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE:
STRENGTH OF THE DESIGNED NOZZLE SERIES · MINIMUM FORCE DISTRIBUTION

TABLE 8 . 12



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Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Comparison Of Radial Strength Of The Nozzle Series

FIGURE No. 8-11

The following are the points worth noting:

- The sketch-designed series cover the existing nozzle spectrum of ice-going ships well.
- The strength (defined as ability to withstand the load without causing yield or excessive deformation), of the nozzles increases with the increase of diameter. The rate of this growth is governed largely by the rate of the increase of nozzle plating thickness.
- The increase of the nozzle's thickness/length ratio is a very effective way of increasing nozzle's strength.
- Robert LeMeur's nozzle seems to be over-designed.
- The rapid increase of the strength for the nozzles of 4 m diameter and higher is attributed to the increase of thickness (see Figure 8.2).

MV Arctic nozzle seems to be under-designed when compared to Canmar's design values yet no damage is reported on the nozzle. This is due to:

- prudent operational procedures;
- "weak" hull, which does not permit operation of the ship at high speeds in heavy ice; and
- Deep submergence of the propeller contribute certainly to the survival of MV Arctic nozzle.

It is not known at this time how to quantify these factors, therefore designing to worst operational conditions for a given ice class is recommended.

In order to express the strength of the nozzles in a simple analytical format suitable for design and regulatory purpose we will now introduce the concept of the generalized bending moment coefficient.

We will define it as:

$$\bar{C}_{BM} = (Z \times \sigma_y)/(F_{max} \times R)$$

where:

F_{max} = the maximum force nozzle can withstand without yielding, as calculated in preceeding paragraphs.

σ_y = the yield stress of nozzle material,

R = the effective radius of nozzle ring ($R = R + 1/2\ S$),

Z = the section modulus of nozzle ring (in x-x direction).

This generalized coefficient accounts for the bending stress, the hoop stress and curvature effects.

Using Table 8.12 for the values of the force, and Table 8.1 for the section modulae for the designed series, we will arrive at:

$$\bar{C}_{BM} = 0.6$$

for all of the nozzles.

This value differs from the maximum bending moment coefficient

$((C_{BM})\max)\max = 0.577$ by 4%.

This multiplier (1.04) is valid for $\theta = 15°$. For other foundation half-angles, we will use the same multiplier, for the following reasons:

1. The stress due to tangential force is at the most 10% of the total stress.
2. The increase of $\theta°$ leads to the decrease of the tangential force.
3. Using tangential force influence contained in the multiplier 1.04 results in a safe value.

In order to account for $\theta°$ other then 15°, the expression derived in section 8.7 will be used.

$$((C_{BM})\max)\max \cong .645 - \theta°/213$$

Substituting into the expression for $\bar{C}_{BM}$, yields.

$$1.04 \times ((.645 - (\theta°/213)) = Z \times \sigma_y/F_{\max} \times R$$

This formula can be converted into the expression for the maximum force:

$$F_{\max} = Z \times \sigma_y/(R \times 1.04\ (.645 - \theta°/213))$$

Replacing Z with the expression derived in Appendix D produces:

$$Z = \kappa \times A_{pl} \times s = \kappa \times \ell \times t_{p\ell} \times s$$

Where κ is the multiplier accounting for the influence of the transverse material on the magnitude of the section modulus. Calculated κ value for the designed series is:

$$\kappa \cong 1.15$$

Rearranging and simplifying, produces:

$$F_{max} = D \times t_{p\ell} \times \sigma_y \times (471/(137 - \theta^\circ) \times (\ell/d)/(1 + D/s))$$

This formulation is very suitable for the prediction of F_{max} in the preliminary design stage. The components of F_{max} are discussed briefly, below.

Diameter, D

Nozzle diameter is usually selected based on the considerations other than the global strength requirements. For example, propulsion efficiency and ship's draft may be the governing factors in selecting diameter.

Plating Thickness, $t_{p\ell}$

Usually this scantling is selected based on considerations other than global strength such as local ice pressure criteria.

Yield Strength, σ_{yield}

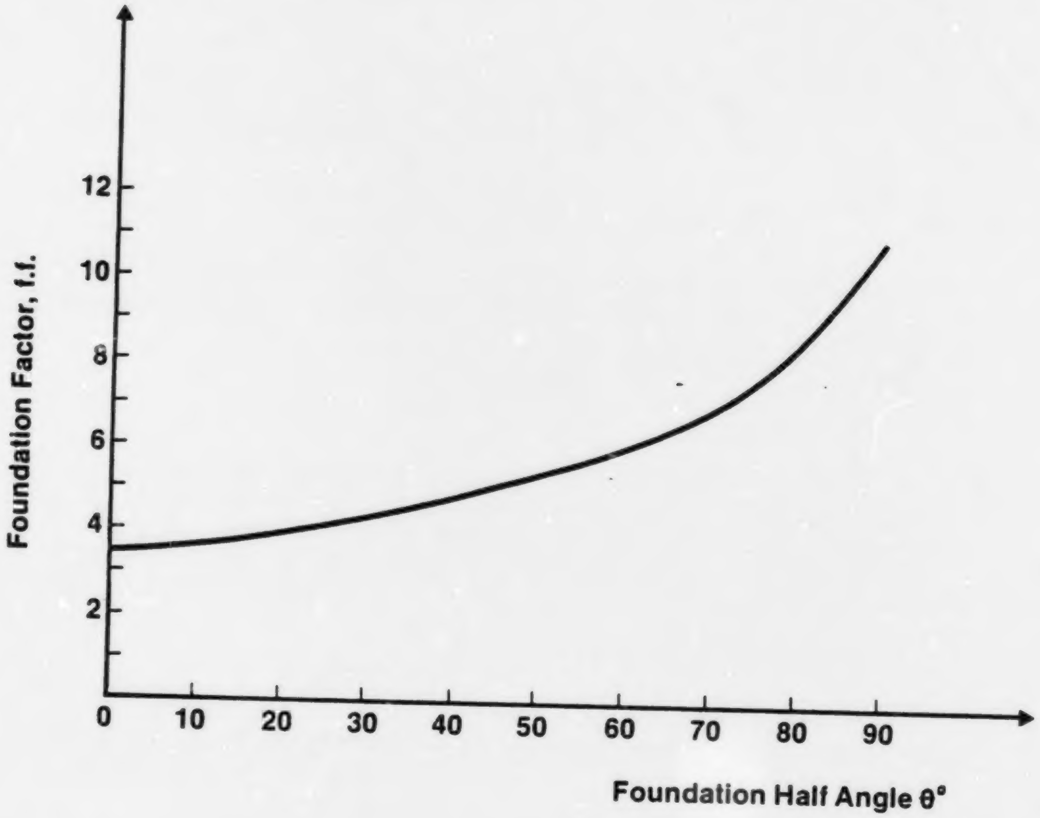
This is the yield strength of steel used.

Foundation Factor, f.f.

This factor, denoted f.f. for convenience, is:

$$f.f = 471/(137 - \theta^\circ)$$

Where θ is the foundation half angle. This factor is given in Figure 8.12, as a function of θ°. Worth noting is that increasing θ° from 0° to 90° increases the f.f. by a factor of 3.



CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE:	Values Of The "Foundation Factor" f.f.
		FIGURE No. 8.12	

Shape Factor, s.f

This factor is defined as:

$$s.f. = (\ell/D)/(1 + D/S)$$

Figure 8.13 represents this function. Worth noting is the fact that even a small change in the shape of the profile (ℓ/D from .5 to .6 and s/ℓ from .2 to .27) leads to a 55% increase of nozzle strength.

Finally, we can express F_{max} as follows:

$$F_{max} = D \times t_{p\ell} \times \sigma_y \times f.f. \times s.f.$$

In words, the maximum force which nozzle ring can withstand without yielding is proportional to:

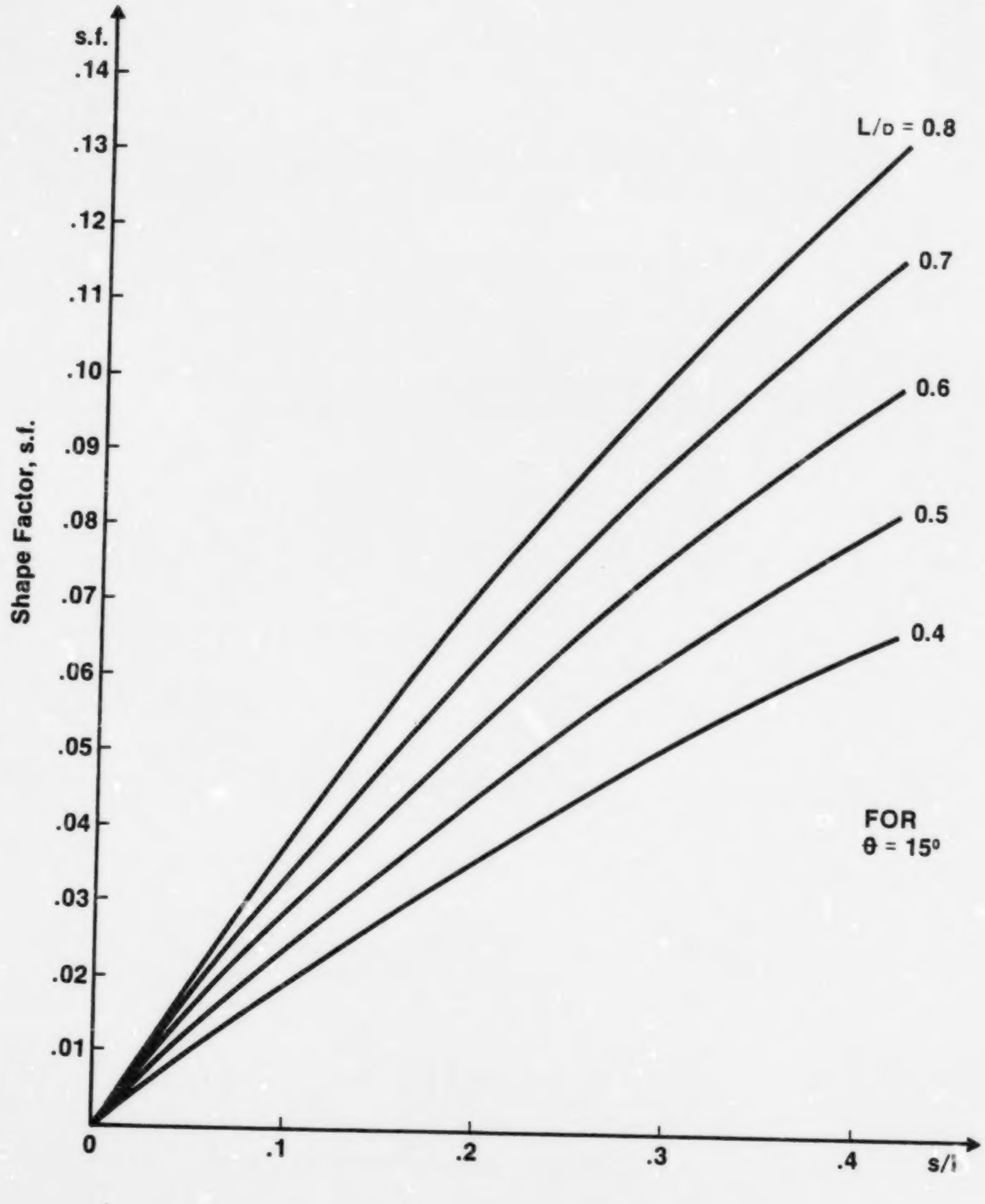
- nozzle diameter,
- plating thickness,
- yield strength of the material,
- foundation factor,
- shape factor.

This formulation was checked against the existing nozzles. The results of the calculations are presented in the following table:

SHIP	NOZZLE DIA [m]	t_{pl} [m]	σ_{yield} [Pa]	ℓ/D [-]	D/s [-]	θ [deg]	F_{calc} [tonnes]
Canmar Kigoriak	5.3	0.035	$.36\text{x}10^9$	.5	11.1	45	1392
R. LeMeur	3.0	0.025	$.36\text{x}10^9$	.5	10.0	90	1230
Supplier 1 & 2	2.8	0.0127	$.24\text{x}10^9$	.617	8.7	64	350
Supplier 7	2.6	0.0125	$.24\text{x}10^9$	.56	9.3	36	200
Arctic	5.4	0.025	$.24\text{x}10^9$	.48	15.4	8.5	347

Influence of the Bottom Support

In order to assess the importance of the bottom support on the nozzle strength, we proceeded as follows:



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Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: Values Of The "Shape Factor" s.f.

FIGURE No. 8.13

1. A simplified expression for C_{BM} was modified to account for large Θ angles. A curve fit exercise gave:

   $$C_{BM} = 0.0003\ (180 - \Theta)^{1.477}$$

   within a few percent accuracy.

2. Assuming a perfectly rigid bottom support the nozzle support angle effectively becomes:

   $$\Theta_{B.S.} = (\Theta + 180)/2 = 90 + (\Theta/2)$$

3. Substituting this angle in the expression for C_{BM} we found that:

   $$(C_{BM})_{B.S.} = 0.0003\ (180 - \Theta/2)^{1.477}$$

4. Thus the ratio of $C_{BM}/(C_{BM})_{B.S.}$ =

   $$(F_{max})_{B.S.}/F_{max} = 2^{1.477} = 2.8.$$

This ratio is approximately (due to approximate nature of the formula) constant.

We concluded that an infinitely stiff bottom support strengthens the nozzle (in bending) by a factor of approximately 2.8.

In such a case other strength aspects may govern (shear area, for example).

In reality, however, there are many other considerations which will lower this factor. Among them:

- The rigidity of bottom support is finite.
- The bottom support may already carry hydrodynamic and ice loading from the rudder.
- A streamlined bottom support is a very important hydrodynamic consideration. Thus increase of its size in order to gain strength is not recommended. Quite the opposite, making it as thin as possible, or eliminating it altogether is desirable from the hydrodynamics view point.

- An accurate assessment of the bottom support effective rigidity requires extensive FEM modelling of the structure, including the stern of the ship.

Therefore, we made the decision to not include the bottom support in our modelling. This error is on the safe side in the radial load cases as we under-estimate the strength of the nozzle.

8.11 An Assessment Of The Vibratory Behaviour Of Nozzles

The dynamic response of the nozzle to ice load is not within the scope of this project. Therefore a cursory "order of magnitude" assessment of vibratory behaviour of the nozzles is made here.

There are two basic types of nozzle vibratory behaviour:

- beam-like, and
- ring-like.

Figure 8.14 shows these types of vibratory behaviour.

Within the ring-like behaviour, further distinction can be made as follows:

- flexural vibrations in the plane of the ring,
- flexural vibrations normal to the plane of the ring,
- torsional vibrations; and
- extensional vibrations,

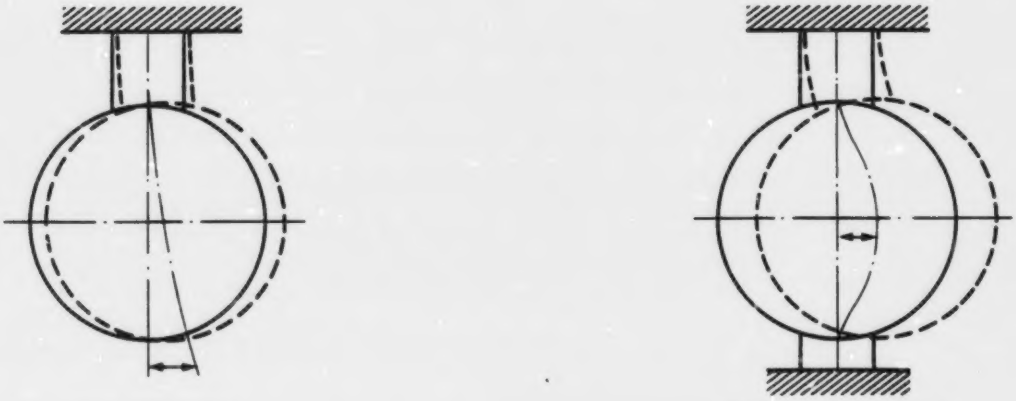
Beam-like behaviour can occur when the nozzle vibrates as a supported beam of varying cross section between two points of the support or as a cantilever beam with varying cross section.

In order to assess the lowest natural frequency of such beams acting as a cantilever, we proceed as follows:

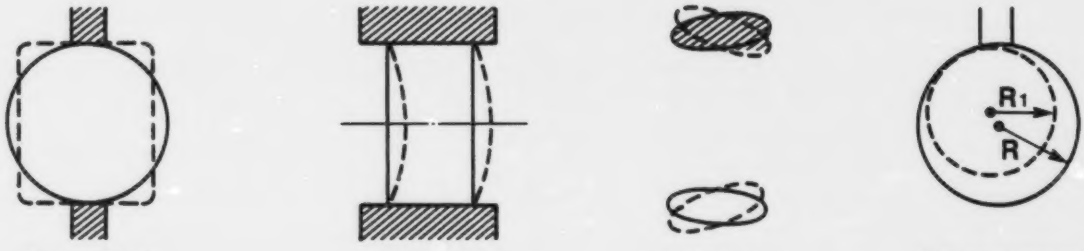
The maximum inertia of the cross section of the beam is $I_{max} = 2 \times A_{\otimes} \times R^2$, where $A_{\otimes}$ denotes the cross sectional area of the nozzle's profile. The minimum inertia of the beam is effectively zero, (or a very small number), in comparison to I_{max}. Therefore the mean inertia of the beam is approximately:

$$I_{mean} = 1/2 \times 2A_{\otimes} \times R^2$$

The natural frequency of a cantilever beam, having length $\ell = 2R$ and the average inertia expressed by the above formula is calculated as:


Top Support Only
Top And Bottom Support

Beam-Like


R1
R
Flexural In Plane
Flexural Normal To Plane
Torsional
Extensional

Ring-Like

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TITLE: Vibrational Behaviour Of Nozzles

FIGURE No. 8.14

$\omega_N = (k)^2 \, (EI_M g/A_M \gamma)^{1/2}$, where

E = is the modulus of elasticity ($E = 2.1 * 10^{11}$Pa for steel)
I_M = average moment of inertia
g = acceleration due to gravity
A_M = average cross sectional area of the beam (in the case of the nozzle, $A_M = 2A_\otimes$)
γ = is the specific gravity of the material of the ring ($\gamma = 79000$ N/m^3 for steel)
$k\ell$ = is the eigenvalue equal to 1.875 for the lowest mode of vibration of the cantilever beam. ($k = 1.875/2R$)
ℓ = is the length of the beam equal to 2R

Substituting the appropriate values, we will obtain:

$\omega_N \cong 3170/R$ [rad/sec]

The following is worth noting:

- The larger the R, the lower the frequency, and
- The frequency is independant of the cross sectional area of the nozzle's profile.

The very high frequency is attributed to the very high stiffness of the nozzle-beam.

The frequency values, expressed in cycles per second are shown below:

R [m]	1	2	3	4
f_v [cps]	504	252	168	126

For the beam supported at both ends, the lowest natural frequency is higher than that shown above (for the same radius).

Propeller excitation frequency is computed as follows:

For a single skeg in front of the propeller the time between blade passes is:

$t = 2\pi R/4 \times 30$ m/s $= R/19$ [sec]

where 4 stands for the number of blades and 30 m/s denotes near-maximum blade tip velocity.

Thus the forcing frequency is $f = 1/t = 19/R$. The values are shown below:

R [m]	1	2	3	4	5
f_p [cps]	19	9.5	6	5	4

Comparing forcing frequencies f_p with response frequencies f_v we can conclude that there is no danger of resonance for the beam-like vibrations of the nozzle, even when the natural frequency is lowered somewhat due to the added mass effect.

Ring-like vibratory behaviour of the nozzle can be evaluated as follows:

Flexural Vibrations in the Plane of the Ring

The nozzle can be thought of as a ring of uniform cross section supported at one or two points. Such a ring will vibrate at higher frequencies than an unsupported ring (analogous to a straight line beam). The frequency of such a freely vibrating ring can be calculated using the following formula:

$$\omega_N = (EgIn^2\ (n^2-1)^2/\gamma A_{\otimes}R^4\ (n^2+1))^{1/2} \qquad \text{[Ref 8.3]}$$

where n, the mode of vibration, has values of 2, 3, 4 [Ref 8.3]; I is the moment of inertia of the cross section of the nozzle. Other variables are the same as before. Substituting, we will obtain, for $n = 2$:

$$\omega_N = 1.4 \times 10^4\ (I/A_{\otimes}R^4)^{1/2}$$

Further calculations are performed in a tabular format:

NOZZLE	(I/AR^4) [1/m]	W_N[rad/sec]	fv[cps]	fp[cps]
1A	0.09	1260	200	19
1B	0.11	1540	240	19
1C	0.13	1820	300	19
2A	0.04	560	90	9.5
2B	0.05	700	110	9.5
2C	0.06	840	130	9.5
3A	0.03	420	70	6
3B	0.04	560	90	6
3C	0.04	600	100	6
4A	0.02	280	40	5
4B	0.03	420	70	5
4C	0.03	500	80	5

Inspection of the above table shows that there is no danger of resonance for the nozzles investigated, even when a reduction of frequencies is made to account for the added mass effect.

Flexural Vibrations Normal to the Plane of Ring

As the inertia of the ring cross section in the y-y direction is several times higher than in the x-x direction, the frequency of vibrations must be higher then previously calculated. Consequently, no resonance is anticipated in this mode of vibrational behaviour.

Torsional Vibrations

Due to the large torsional stiffness of bottom and top support, no vibrations of practical importance are anticipated in this mode.

Extensional

For this mode, the frequency can be calculated as follows:

$$\omega_E = (Eg/\gamma R^2)^{1/2}$$

where variables are the same as denoted above. Substituting, we will have:

$$\omega_E = 5.1 \times 10^3/R$$

Thus extensional vibrations have a frequency higher than the flexural vibrations in the plane of the ring.

In concluding this cursory assessment of vibratory behaviour of the nozzles, we believe that there is no danger of resonance for the designed nozzle series.

8.12 An Assessment Of The Buckling Behaviour Of Nozless

8.12.1 Global Buckling

In order to assess the global buckling potential, five loading scenarios were conceived, as illustrated in Figure 8.15. These scenarios are in effect the worst possible scenarios from the viewpoint of the global buckling.

Scenario 4 was found to produce the highest compressive tangential force:

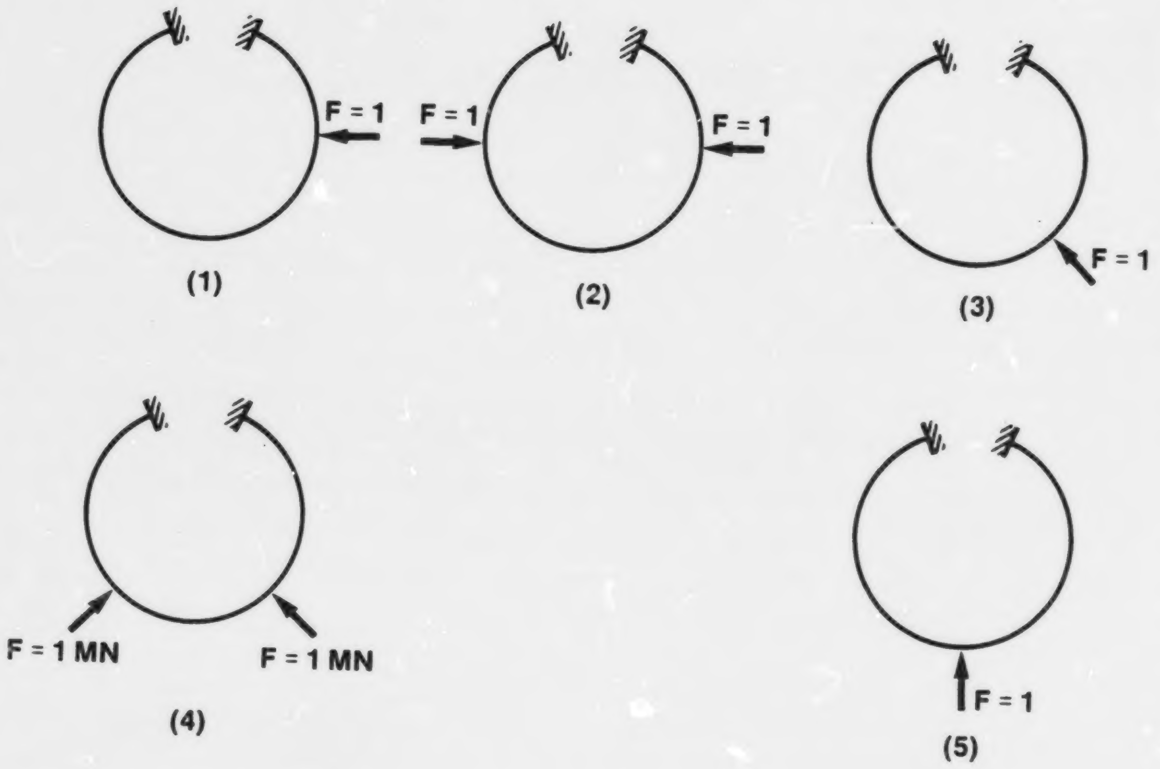
$$(C_{TF})_{max} = -0.713 \text{ (compression)}$$

This value is very close to the maximum tangential force coefficient value for the side impact $C_{TF} = -0.706$ ($\Theta = 15°$) as shown in Table 8.3.

Buckling pressure q_{cr} is calculated using the formula (Ref 8.1):

$$q_{cr} = 3EI/R^3$$

Substituting the values for an actual nozzle in the equation above (see section 8.2 for nozzle definition):



F = 1
(1)
F = 1
F = 1
(2)
F = 1
(3)
F = 1 MN
F = 1 MN
(4)
F = 1
(5)

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Strength Requirements
For Nozzles For Ice
Transiting Ships

Load Cases For Global Buckling Strength Investigations

FIGURE No. 8.15

$E = 20.710^{10}$ Pa

$I = 0.019$ m^4

$R = 3.3$ m

we will obtain q = 333.1 MN/m, which corresponds to a force:

$$P_{cr} = q_{cr} \times \sqrt{} 2 \times R = 1554 \text{ MN}$$

This force is much higher then any ship can generate.

It should be noted that the formula for buckling pressure given by:

$$q_{cr} = 3EI/R^3$$

is exact only for a ring under the action of uniformly distributed radial external pressure. Due to the similarity of the tangential force distribution in the load cases investigated to the tangential force distribution of a uniformly distributed load, the above formulae will be applied as an approximation.

Consequently, it is concluded that there is no danger of global buckling of the nozzle ring due to ice pressure.

To check yielding under the tangential force the following formula is used:

$$\sigma = TF/A + M_u R/Z$$

Where:

TF = the tangential force, MN
A = the section area,
M_u = the bending moment in a ring with unit radius,
R = the radius of the nozzle ring, and
Z = the section modulus of the section.

Table 8.13 gives the factors of safety against first yield when F = 1 MN in all the given cases of loading. A value of 360 MPa was used as the yield strength of the material. Load Scenario 1 gives the lowest safety factor or lowest load (5.51 MN) to produce first yield in the nozzle.

8.12.2 Local Buckling

Local buckling was examined by calculating the

CASE OF LOADING	TF	M	σ_{max}, MPa	σ_y/σ_{max}
1	-0.704	-0.555	-31.74	11.03
2	-0.52	-0.221	-13.58	25.77
	+0.462	+0.162	-10.27	34.06
	0	+0.298	±15.56	22.5
3	-0.53	-0.243	-14.77	23.70
	+0.05	+0.34	+17.94	14.51
	+0.189	+0.477	+25.64	13.65
4	-0.713	-0.139	-10.06	34.78
	-0.296	+0.279	-13.4	22.25
5	-0.5	-0.154	-10.01	34.77
	0	+0.291	±15.19	23.04

TITLE:
COMPARISON OF YIELD AND
BUCKLING STRENGTHS

TABLE 8.13

maximum compressive stresses developed in the shell plate due to bending moment and tangential force. The following formula for simply supported plate, Figure 8.16a applies (Ref. 8.1):

$$\sigma_{cr} = k * E/(1-\nu^2) * (t/b)^2$$

Where:

ν = Poisson's ratio (= 0.3),
t = the plate thickness,
b = the width of the plate (1000 mm) where the load is applied, and
k = a constant dependent on the aspect ratio (a/b) of the plate.

For frame spacings of 300 mm, and 600 mm, representing practical bounds, the critical stress is 3213 MPa and 1247 MPa, respectively. These values are several times higher than the yield strength suggesting that yielding will occur first.

The local buckling strength of the shell plating was assessed using formulas for flat plates. In reality this plate is curved and will therefore undergo a beam-column effect rather than pure buckling. For the structure of the nozzle under investigation the results showed that instability is highly unlikely for such a structure. It was therefore found unnecessary to check the beam column effect since the shear forces are resisted mainly by the webs rather than the shell.

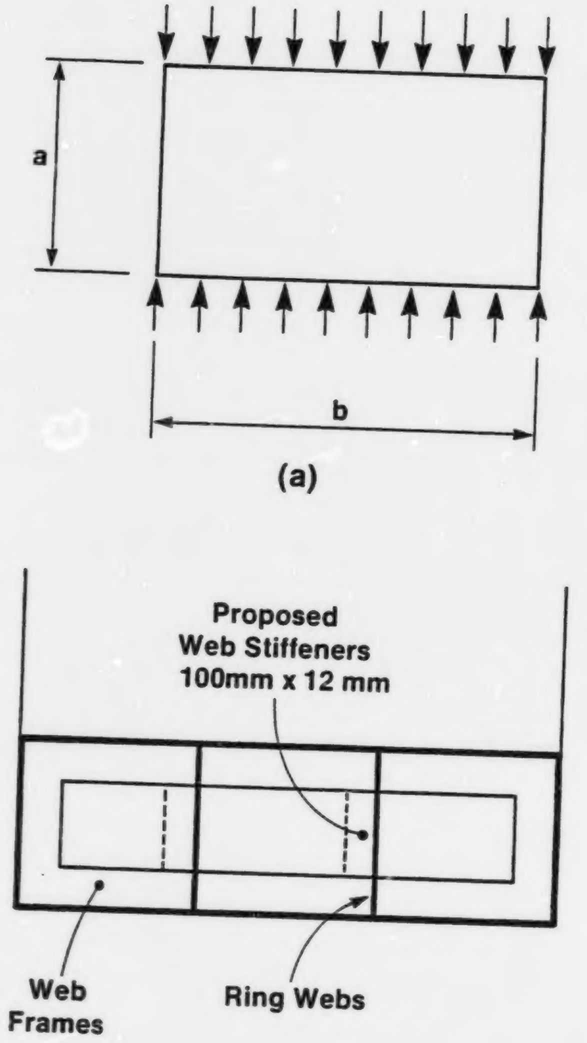
The conclusion is therefore that buckling will not be a problem for a heavy structure such as that of the nozzle.

In order to guarantee that local buckling does not occur at the intersection between the framing and the ring webs, the ring webs should be stiffened by small flat bars (100 mm x 12 mm) as shown in Figure 8.16b).

8.13 Conclusions From Analytical Modelling

1. Nozzle structural behaviour can be modelled by thin, curved beam theory. The shear and tangential force effects on the nozzle behaviour are small and can be ignored.

2. The curvature effect is provided for by the use of stress multipliers for outer and inner fibers. The correction amounts to less than 5%.


a
b
Proposed
Web Stiffeners
100mm x 12 mm
Web
Frames
Ring Webs

(a)

(b)

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Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: **Local Buckling Case**

FIGURE No. 8.16

3. Any nozzle structural response can be predicted by using the response of a nozzle of 1 unit radius acted upon by 1 unit force (nondimensional bending moment, shear force, hoop force and displacement coefficients), multiplied by the actual nozzle characteristics, and the actual force as follows:

- Bending Moment = $C_{BM} \times F \times R$
- Shear Force = $C_{SF} \times F$
- Tangential Force = $C_{TF} \times F$
- Deflection = $C_\delta \times FR^3/EI$

4. Shear force and tangential force do not change with nozzle radius (all other parameters being constant).

5. Side impact is more severe then the bottom impact.

6. The maximum bending moment occurs at the foundation support closest to the point of force application.

7. The maximum bending moment occurs when the force is applied 105° from the bottom centerpoint (see Figure 8.9).

8. Increasing the foundation angle decreases the magnitude of the maximum bending moment. The approximate formulation is:

$$C_{BM} = 0.645 - \theta^\circ/213$$

where θ is the foundation angle, in degrees.

9. Maximum shear force and tangential force coefficients do not occur at the point of maximum C_{BM}.

10. Compressive stresses are much larger than tension stresses. The inner ring plating is in compression.

11. The total stress in compression is the sum of the stresses due to bending and tangential stresses.

12. The segment of the nozzle between the point of load application and the foundation closest to it is the most stressed section.

13. Small foundation angle changes do not offer significant reductions to the maximum bending moment. The ratio of (C_{BM})max for $\Theta = 0°$ to (C_{BM})max for $\Theta = 90°$ is 2.68.

14. The part of the nozzle ring closest to the foundation is much more stressed then the "free" part, regardless of the point of load application.

15. Shear force grows with the increase of foundation angle.

16. The maximum deflections of the ring do not occur at the point of load application, but near to it.

17. Deflections decrease nearly linearly with the increase of foundation angle.

18. Load spreading does not lead to a significant decrease of the maximum bending moment coefficient and can be omitted from further considerations.

19. The magnitude of bending moment coefficients for an axial load is similar to the radial load C_{BM}. Stresses in the axial load case are smaller by a factor of 2 to 3 due to the difference in section modulus.

20. Twisting moment coefficients and bending moment coefficients decrease with an increase of foundation angle Θ for the axial load case.

21. For the axial load case, the higher the torsional stiffness, the smaller the bending moment coefficient becomes.

22. For the axial load case, nozzle strength is governed by the combination of torsion and bending stresses. The shear stress contribution is not significant.

23. A bottom support offers a significant reduction of stresses in the axial load case.

24. For the sketch-designed series, bending stresses are the limiting factor of nozzle strength.

25. The radial loading is more severe then the axial one, i.e. the nozzle strength for axial load is approximately twice of the radial case.

26. Nozzle strength, ie ability to carry ice load without yielding or excessive deformations, can be expressed in the following form:

$$F_{max} = D * t_{pl} * \sigma_y * (471/(137-\theta^\circ) * ((\ell/D)/(1+D/S))$$

27. For a 15° half foundation angle, conventional nozzle design ($\ell/D = 0.5$, $s/\ell = .2$), the nozzle strength is 310 tonnes for a 2 m diameter nozzle and 2162 tonnes for an 8 m diameter nozzle.

28. Increasing the thickness of the nozzle profile is an effective means of increasing the nozzle strength. For a 2 m diameter nozzle, increase of the profile thickness by 50% increase the strength by 70%.

29. Increase of the profile thickness was found not to significantly degrade the hydrodynamic performance of the nozzle.

30. The strength of a fully bottom supported nozzle is approximately three times higher than an unsupported nozzle.

31. The calculated natural vibration periods for nozzles are much higher then propeller excitation frequencies. Therefore, vibration problems with ice strengthened nozzle are not expected.

32. Buckling strength of the nozzle is high. Therefore yielding in compression will occur before buckling.

8.14 List Of References For Chapter 8.0

8.1 Formulas for Stress and Strain, by R.J. Rourke. McGraw-Hill Book Company, 1965.

8.2 Theory of Elasticity, by Timoshenko. McGraw-Hill.

8.3 Shock and Vibrations Handbook, edited by C. M. Harris and C. E. Crede. McGraw-Hill, 1976.

9. FEM MODEL

9.1 Introduction

In order to assess the validity of the analytical model based on thin curved beam theory, a 3D FEM program was executed. As FEM modelling is a "state-of-the-art" engineering tool, the only work needed to be done was the adaptation of the existing FEM programs for handling of nozzle-like structures. The basic FEM program chosen was SAP IV, which is a commercially available, well tested, FEM program. For this program, a computer subroutine was developed enabling the user to input any nozzle/load scenario desirable. The subroutine (detailed in Appendix B) permits a complete definition of the nozzle to be input with the minimum amount of effort. A full definition of:

- Nozzle;
- Foundation; and
- Load,

is then input into SAP IV for stress and deflections calculations at any point of the nozzle or foundation. The subroutine can handle any nozzle geometry, foundation geometry and any load application geometry.

The load case summary is given in Table 9.1.

Runs were so arranged as to test several parameters of nozzle/load configuration.

Parameters to be tested were:

- Effect of change of the diameter of the nozzle on the magnitude of the bending moment coefficient (C_{BM}), the shear force coefficient (C_{SF}) and the tangential force coefficient (C_{TF}) for a constant thickness of the ring of the profile.
- Effect of changing nozzle thickness for constant inner diameter on: C_{BM}, C_{SF} and C_{TF}.
- Severity of side versus bottom impact.
- Effect of the foundation angle on the magnitude of C_{BM}, C_{SF} and C_{TF}.
- Influence of radial versus axial load on the magnitude of C_{BM}, C_{TF} and C_{SF}.
- Influence of the foundation stiffness on the magnitude of the stresses.

	NOZZLE				LOAD	
RUN NR	Radius (m)	Found Angle (°)	Thickness (m)	Angle of Application (°)	Spread Angle (°)	Radial/Axial -
1	6	2 x 15	.75	90	10	Radial
2	3	2 x 15	.60	90	10	Radial
3	3	2 x 15	.75	90	10	Radial
4	3	2 x 15	.90	90	10	Radial
5	3	2 x 15	.75	0	10	Radial
6	3	2 x 15	.75	0	40	Axial
7	3	2 x 15	.75*	0	40	Axial
8	3	2 x 30	.75	0	10	Radial

* Foundation plates thicknesses were multiplied by a factor of 10.

TITLE:
FEM LOAD CASE SUMMARY

TABLE 9.1

The basic nozzle configuration corresponds to the series 3B (see Figure 8.1).

The foundation angle of 2 x 15° corresponds to what is considered to be a good design practice. For simplicity sake, plating thicknesses were set to be 36 mm, constant in all of the members.

A drawing of the simplified structure of the nozzle is shown on Figures 9.1 and 9.2. No bottom support effect has been included. Results are presented for 9 selected locations along the ring.

Simplification of the nozzle ring to be used in FEM was done for the following reasons:

- Nozzle is essentially a ring. The simplest ring one can envisage is a thick cylinder. It is obvious that the global strength of the nozzle can be modelled by means of a thick cylinder, while the local strength cannot.
- Detailed FEM modeling is expensive and time consuming. Such modelling must reflect a particular detailed design of the nozzle structure and therefore, cannot be representative of other nozzles.
- A comparison of detailed FEM model with general analytical model cannot be made for the reason outlined above.
- Instead of spending effort on detailed FEM modelling, the effort was allocated to more in-depth analysis of general properties of structural response of ring-like nozzles.

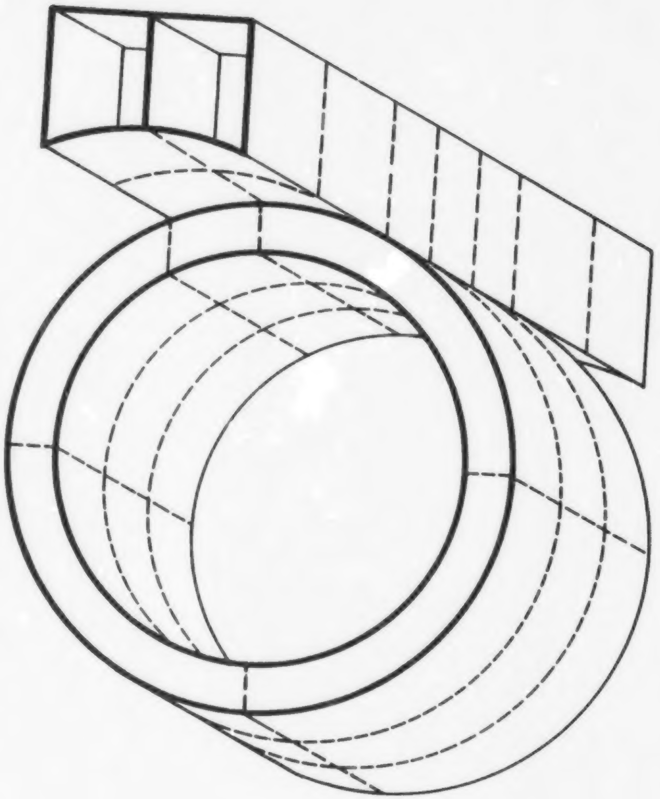
9.2 Sensitivity Runs

Results of Runs 1 and 3 show the variation of bending moment, shear force and normal force distribution for the 12 m and 6 m diameter nozzles, respectively. The difference in maximum values between those two nozzles are:

$$[(C_{TF})_3/(C_{TF})_6] = 1.012$$

$$[(C_{SF})_3/(C_{SF})_6] = .99$$

$$[(C_{BM})_3/(C_{BM})_6] = 1.01$$



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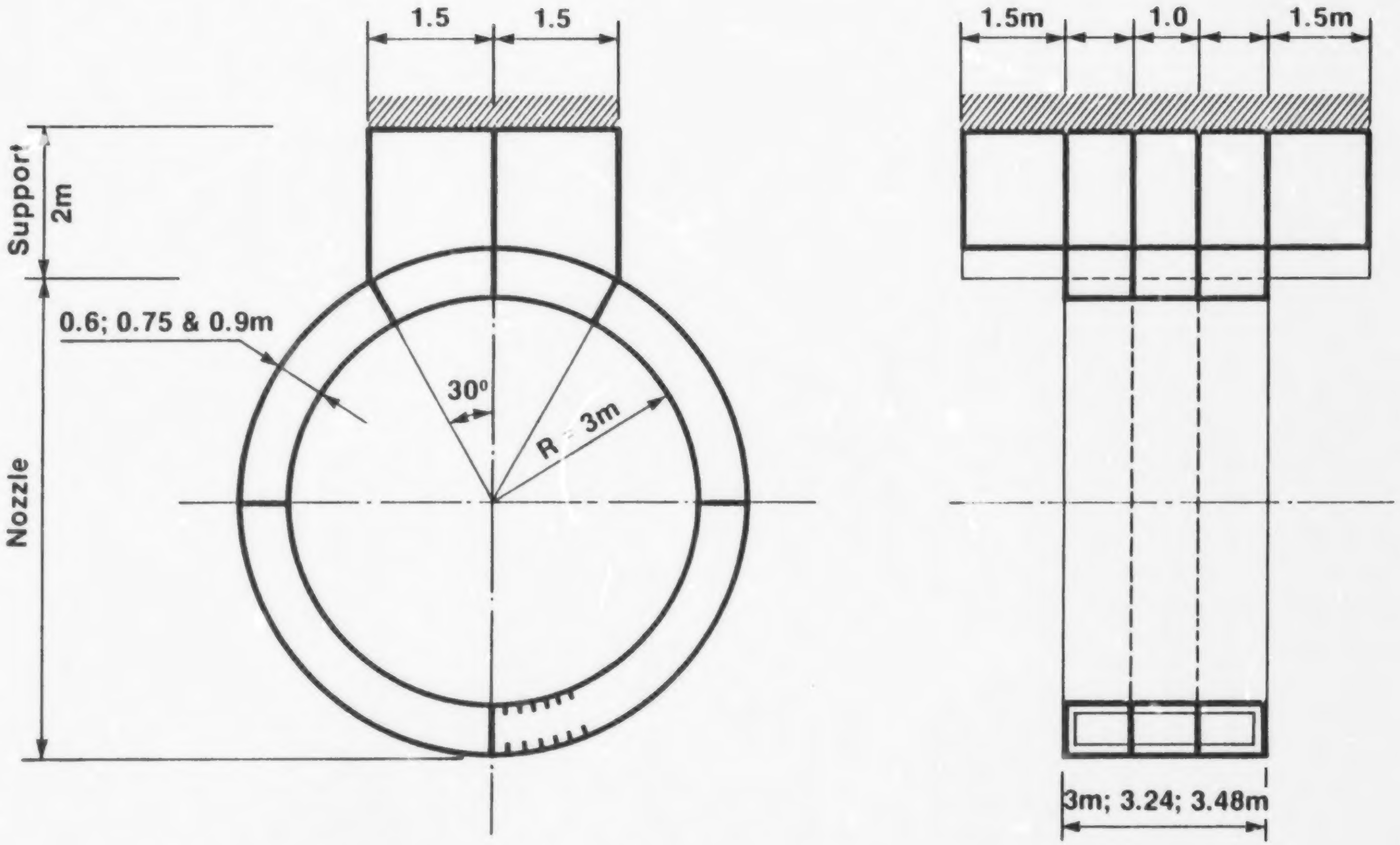
For Nozzles For Ice
Transiting Ships

TITLE: Sketch Design Of Nozzle
Structure For FEM Modelling

FIGURE No. 9.1


1.5
1.5
Support
2m
Nozzle
0.6; 0.75 & 0.9m
30°
R = 3m
1.5m
1.0
1.5m
3m; 3.24; 3.48m

Outer Skin { Nozzle: PL 36 mm, Long'ls 200 x 36 F.B., 300 SPG, 1000 Span

Support: PL 27 mm, Long'ls { 300 x 27 F.B., 300 SPG, I.W.O. 1500 Span
200 x 27 F.B., 300 SPG, I.W.O. 1000 Span

CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Scantlings Of The Nozzle For FEM Investigation FIGURE No. 9.2

These differences are so small that they can be ignored. Larger percentage differences occur for small values of C_{TF}, C_{SF}, C_{BM}. However, those values are not of importance to the strength considerations of nozzles.

Runs 2, 3 and 4 show the difference in bending moments, shear forces and normal forces due to the increased profile thickness:

A summary of the thickness effect is shown below:

Run #	s/ℓ	$(C_{TF})_{Max}$	(C_{SF}) Max	(C_{BM}) Max
2	.20	.660	.614	.470
3	.25	.666	.654	.502
4	.30	.666	.655	.501

Thus, for a 50% change of the profile thickness/length ratio, the values of C_{TF}, C_{SF} and C_{BM} remain constant within 6% accuracy.

This confirms the validity of analytical model based on the thin curved beam theory.

Runs 3 and 5 compare the side impact with the bottom impact:

	SIDE IMPACT		BOTTOM IMPACT	
	FEM	Analytical	FEM	Analytical
(C_{TF}) Max	-.666	-.706 *	-.500	-.500**
(C_{SF}) Max	.654	0.783	0.468	0.500
(C_{BM}) Max	-.502	0.556	+.270	+.291

* Table 8.3

** Table 8.5

The following points are worth noting:

- Side impact is more severe than the bottom one.

- The analytical model predicts the bottom impact well, while it over-predicts the side impact values. This is due to the proximity of the foundation which, for the analytical model has an infinite stiffness. For the side impact, where maximum bending moments occur near the foundation, this influence is more pronounced.

Runs 5 and 8 compare the influence of nozzle foundation angle for the radial load application:

Bottom Impact:

Foundation Angle:	$(C_{TF})_{Max}$	$(C_{SF})_{Max}$	$(C_{BM})_{Max}$
2 x 15	-.500	-.468	+.270
2 x 30	-.496	-.440	+.210

Thus doubling of the foundation angle decreases the bending moment coefficient by 28%.

The analytical model gives:

2 x Θ	C_{BM}
2 x 15	C_{BM} = .270,
2 x 30	C_{BM} = .228,

at the foundation.

Runs 5 and 6 compare radial and axial load applications of the same magnitude on the structural response of the nozzle. Due to the small axial area available, load spread is larger than in the radial case.

	$(C_{TF})_{Max}$	$(C_{SF})_{Max}$	$(C_{BM})_{Max}$
Radial	-.500	-.468	+.270
Axial		-.499	+.670 *

* Note that this bending moment acts in the direction perpendicular to the radial bending moment direction.

Runs 6 and 7 compare the influence of the foundation stiffness on the magnitude of C_{SF}, torque coefficient C_Q and C_{BM}.

Foundation Thickness	$(C_{SF})_{Max}$	$(C_Q)_{Max}$	$(C_{BM})_{Max}$
t	-.499	.799	.670
10 x t	-.499	.795	.760

As expected, the value of maximum bending moment (Y - Y axis) grew with the increase of the foundation stiffness.

The analytical model predicted values are:

Infinite Foundation Thickness	$(C_{SF})_{Max}$	$(C_Q)_{Max}$	$(C_{BM})_{Max}$
	-.500	.835	.757

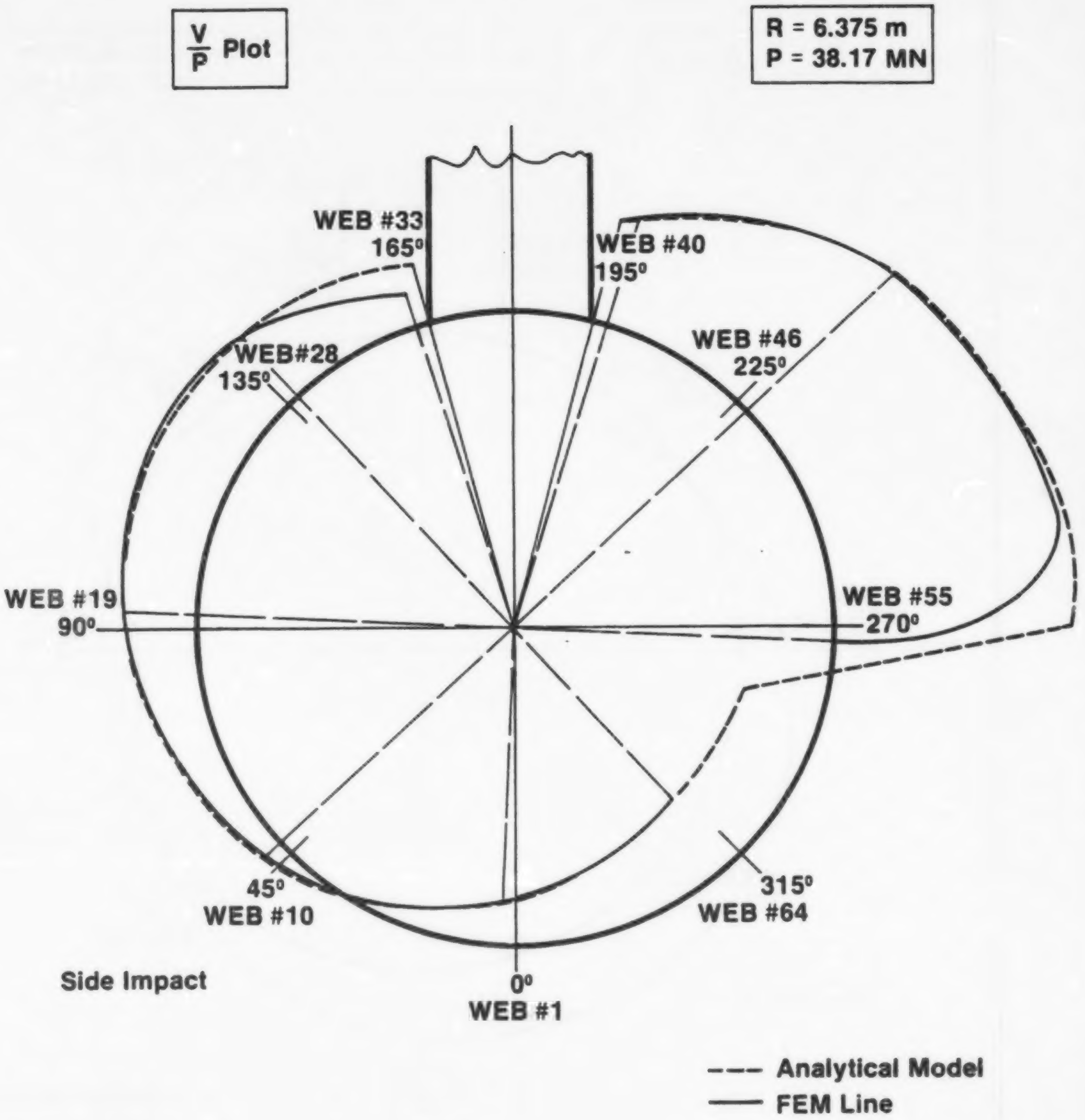
Thus a good agreement exists between the analytical and FEM model for the axial load case.

Figures 9.3, 9.4 and 9.5 show the comparison of C_{SF}, C_{TF} and C_{BM} distribution between the FEM and analytical models. The agreement is excellent, except near the foundation and at the point of load application. The FEM modelled foundation is "softer" than the infinitely stiff analytical model foundation. The point of the load application shows some discrepancies due to the local load distribution effect.

Table B.2 contained in Appendix B, shows FEM calculated values of normal force, shear force and bending moments in selected locations along the ring.

9.3 Deflections

The deflections of the nozzle ring under applied loads are summarized below. All deformations are calculated at the point of load application.



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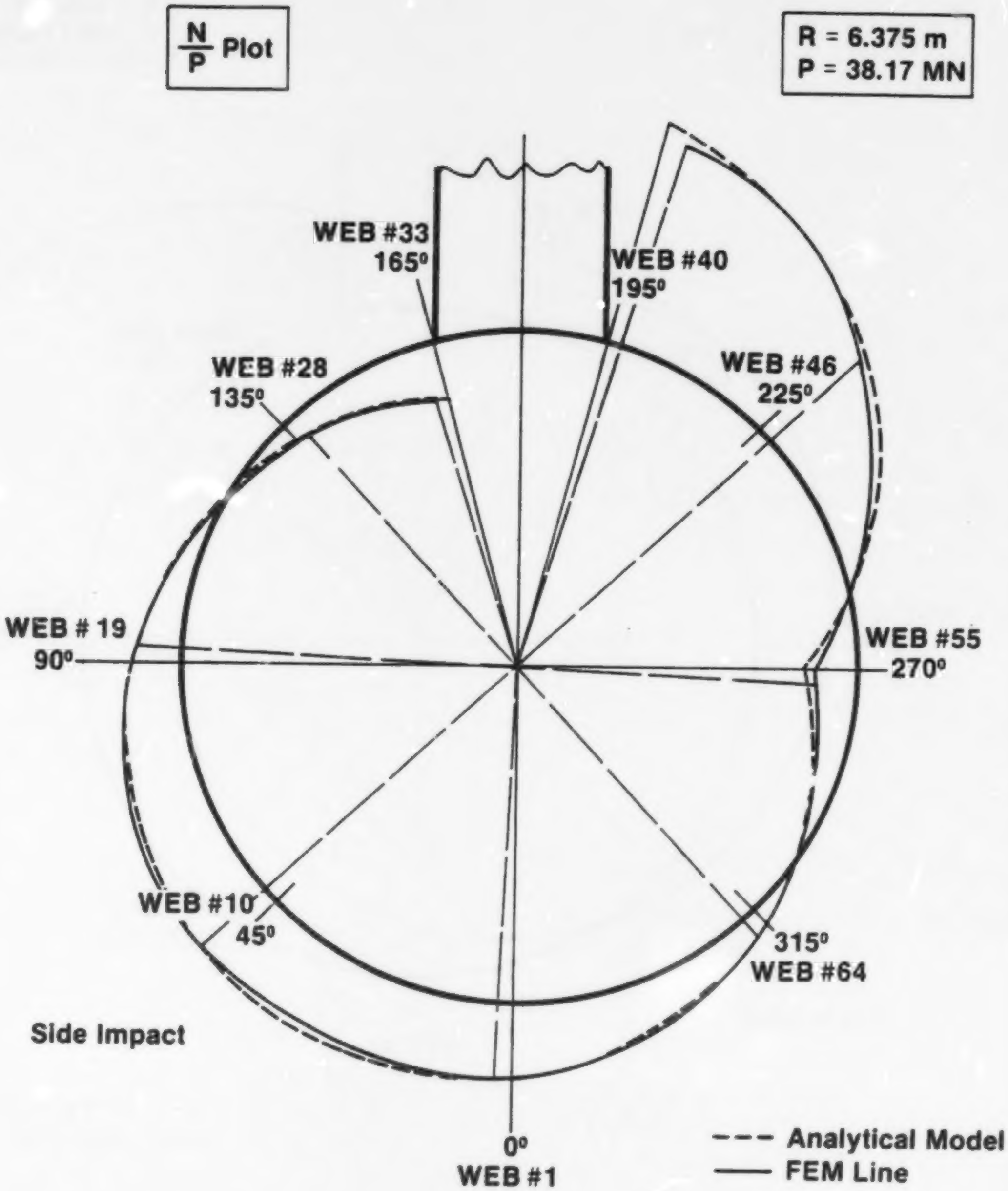
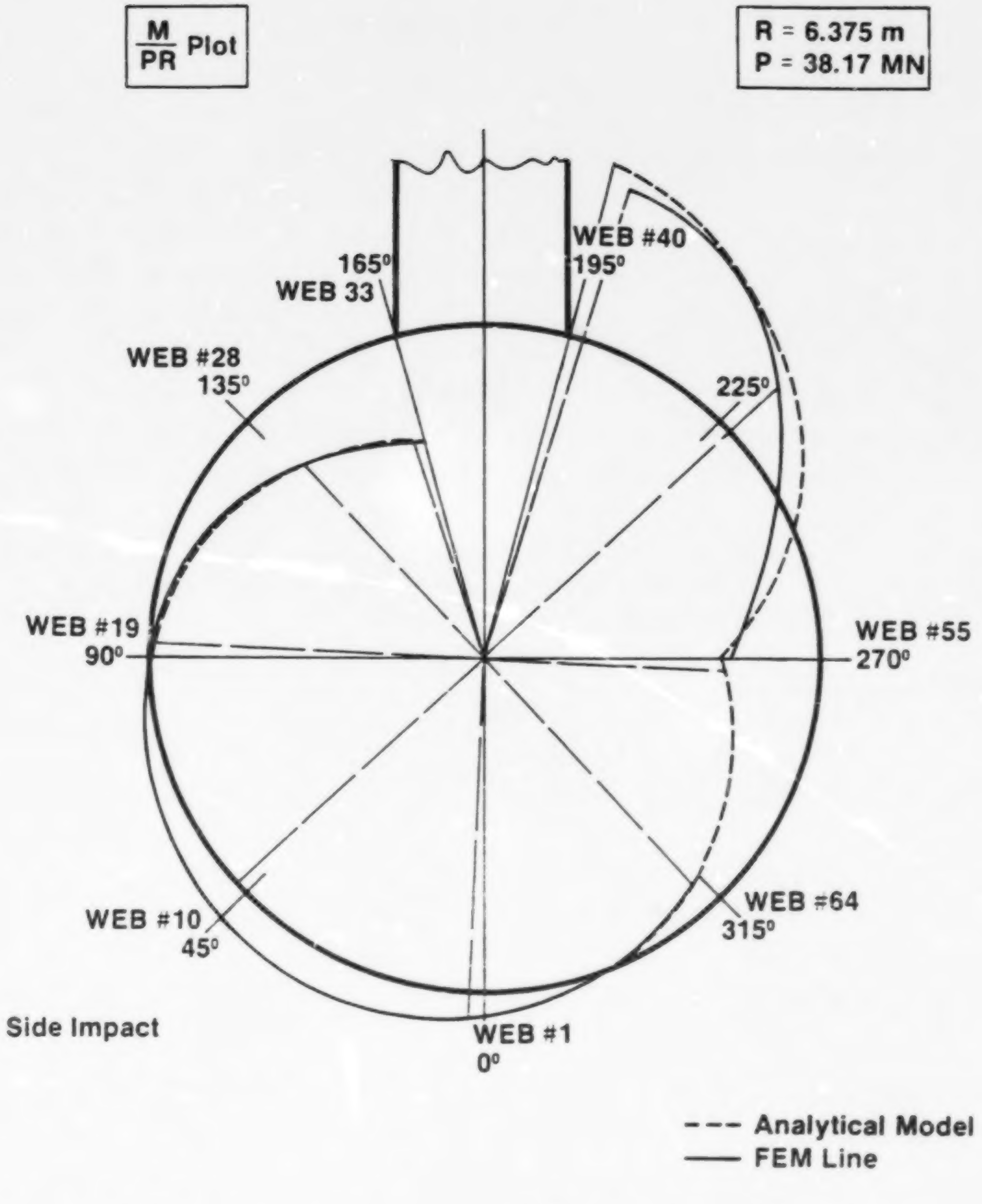
Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Comparison Of Shear Force Distribution Predicted By FEM and Analytical Model

FIGURE No. 9.3



CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Comparison Of Tangential Force Distribution Between FEM And Analytical Model FIGURE No. 9.4



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Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: Comparison Of Bending Moment Distribution Between FEM And Analytical Model

FIGURE No. 9.5

TRANSVERSE WEB NUMBER

RUN NO.	1		2		3		4		AVERAGE	
	δy*	δz	δy	δz	δy	δz	δy	δz	δy	δz
1	-.40	-.236	-.4	-.236	-.4	-.236	-.40	-.236	-.4	-.236
2	-.0675	-.0377	-.0675	-.0378	-.0675	-.0378	-.0675	-.0378	-.0675	-.0377
3	-.059	-.0325	-.059	-.0325	-.059	-.0325	-.059	-.0325	-.059	-.0325
4	-.05	-.027	-.05	-.027	-.05	-.027	-.05	-.027	-.05	-.027
5	0.00	0.02	0.0	0.02	0.0	0.02	0.0	0.02	0.0	0.02
6	0.0702	0.024	0.07	0.007	0.07	0.007	0.07	0.024	0.07	0.016
7	0.057	0.021	0.057	0.006	0.057	0.006	0.057	0.021	0.057	0.013

* δx, δy, δz denote linear displacements, in meters, of the inner ring at the centre of load application area, in x, y, z directions respectively.

Comparison of the FEM calculated deflections with those given by analytical model is given below:

Run No.	(δ_N)FEM [m]	$(C\delta_N)$analytical [-]	$(\delta_N)_3$	(δ_N)analytical)/ (δ_N)FEM
1	0.4	.228[1]	0.27	.67
2	0.0675	.228	0.036	.59
3	0.059	.228	0.022	.37
4	0.050	.228	0.016	.32
5	0.02	.104[2]	0.01	.50

Notes:

1. See Table 8.3, $\Theta = 15°$
2. See Table 8.5, $\Theta = 15°$
3. $\delta_N = C_{\delta N} \times [(F \times R^3)/EI]$

FEM gives the ratio 1.15. This suggests that there are other components of FEM deflections which remain unchanged.

FEM deflections are the sum of:

1. Deflections due to foundation movement.
2. Global deflections of the ring only (analogous to analytical).
3. Local deflections under the load.

The deformations of the nozzle ring at the foundation near the point of load application are tabulated below:

Run #1	δ_y	δ_z	δ_y	δ_z
	INNER SHELL		OUTER SHELL	
Ring #				
1	-.0136	-.0007	-.0011	-.0028
2	-.0143	-.0011	-.0005	-.0037
3	-.0143	-.0011	-.0005	-.0037
4	-.0136	-.0007	-.0011	-.0028

Run #2				
Ring#				
1	-.0081	-.0011	-.0028	-.0019
2	-.0085	-.0011	-.0028	-.0021
3	-.0085	-.0011	-.0028	-.0021
4	-.0081	-.0011	-.0028	-.0019

Run #3	δ_y	δ_z	δ_y	δ_z
	INNER SHELL		OUTER SHELL	
Ring #				
1	-.0085	-.0011	-.0028	-.0019
2	-.0089	-.0011	-.0029	-.0021
3	-.0089	-.0011	-.0028	-.0021
4	-.0085	-.0011	-.0028	-.0019

Run #4

Ring #				
1	-.0088	-.0011	-.0028	-.0020
2	-.0092	-.0011	-.0029	-.0021
3	-.0092	-.0011	-.0029	-.0021
4	-.0088	-.0011	-.0028	-.0020

The influence of the deformation of the foundation on the displacement of the ring at the point of load application may be assessed by using the approximate formula:

$$\bar{\delta} = 2R\,y\,(\cos\Theta)/(\tan(\pi/4 + \Theta/2)a)$$

where y is the difference, in meters, between inner and outer shell displacements in the y direction at the foundation, and a is the thickness of the ring.

Taking Web #2 as a representative for the whole ring, and setting $\Theta = 15°$, we will arrive at:

Run #	1	2	3	4
$\bar{\delta}$	-.17	-.05	-.04	-.03
δ_{tot}	-.40	-.0675	-.059	-.05
$\delta_{tot}-\bar{\delta}$	-.23	-.0175	-.019	-.02
$\delta_{analytical}$	-.27	-.036	-.033	-.016

The influence of the vertical deformation of the foundation on the displacement of the ring can be assessed in a similar fashion.

It is evident that the foundation is too weak (stiffness is too low), which leads to the deformations exceeding the propeller tip clearance for the applied load of 2000 tonnes.

9.4 Conclusions Derived from FEM Modelling

1. The influence of radius of the nozzle ring on the values of C_{BM}, C_{SF} and C_{TF} can be ignored.

2. The influence of the profile thickness on the magnitude of C_{BM}, C_{SF} and C_{TF} is very small and can be ignored.

3. The analytical model over-predicts the bending moment coefficient at the foundation by approximately 10%. This is due to the foundation stiffness effect.

4. The FEM and analytical models show a very good agreement in C_{BM}, C_{SF} and C_{TF} everywhere in the ring, except at the foundation.

5. The axial load case shows good agreement between the FEM and analytical modelling, among others, due to high stiffness of the foundation in X-X direction.

6. Deflections predicted by FEM are up to twice those predicted analytically. This is due to the influence of the foundation stiffness and local deformations on the total deflections of the nozzle ring. The foundation used was too weak.

7. FEM bending moments are calculated from the stresses. Agreement between FEM and the analytically derived BM proves that the stresses calculated by those two models are in reasonable agreement. Further, this proves that there is no need to make a correction for the effective flange width, as suggested in 8.3.

10. SUGGESTED REQUIREMENTS FOR REGULATORY BODY CONSIDERATIONS

10.1 Introduction

The design of nozzles for icebreaking ships is a relatively new domain of naval architecture. Design standards are not yet established and the field is open to novel, maybe radically different solutions.

Therefore, it is felt that at this time two parallel approaches should be taken:

- First, giving a designer the set of ice loads and safety factors required to produce failure-free nozzle design. The regulatory body then approves the design submitted based on a given criteria. For example, criterion of not reaching 75% of the yield stress in any structural member.
- Second, giving a designer all the information needed to fulfill the criteria. For example, giving the required section modulus, shear area and plating thickness for a given size and ice class of the ship.

This philosophy is illustrated on Figure 10.1.

10.2 Nozzle Safety Criteria

Two factors decide on the safe performance of the nozzle:

- Ability to sustain loads without being damaged to the extent requiring repairs.
- Ability to sustain loads without deformations large enough to cause damage to propellers.

The first requirement stipulates that the stresses in the nozzles's structural components should not exceed a certain value. The value can be the yield strength or the ultimate strength. At this time however, design to the yield is recommended due to:

- Large uncertainty of the loads.
- Plastically deformed nozzle ring must be repaired as soon as possible in order to prevent serious damage to the nozzle and or propellers.

Further, the distinction is made between the local and global structural requirements. Global requirements are:

- Adequate section modulus and adequate inertia of nozzle ring's cross section to assure sufficient strength and deflections within permissible deformations, and
- Adequate shear area.

Local Requirements Are:

- Adequate plating thickness, section modulus of the supporting stiffeners and web thickness to prevent shear/buckling instability under the ice load.

Since the pressure area/curve to be used is the same as used for the stern part of the ship (there is no reason to used a different curve), then the local scantlings of the nozzle should be determined the same way as the stern scantlings, provided the structural safety of the nozzle in enhanced by a suitably selected safety factor reflecting the essential function of the nozzle as opposed to the less essential function of the stern.

This essentiality is based on the fact that the serious damage to the nozzle will lead to serious damage of the propulsion train and may lead to immobilization of the ship.

Adequate top and bottom supports.

Two aspects of this requirement are:

- Sufficient shear area to carry the force into the foundation. Sufficient torsional stiffness to carry the torque from the axial load.

- Sufficient stiffness (inertia) to prevent large deformations of the support.

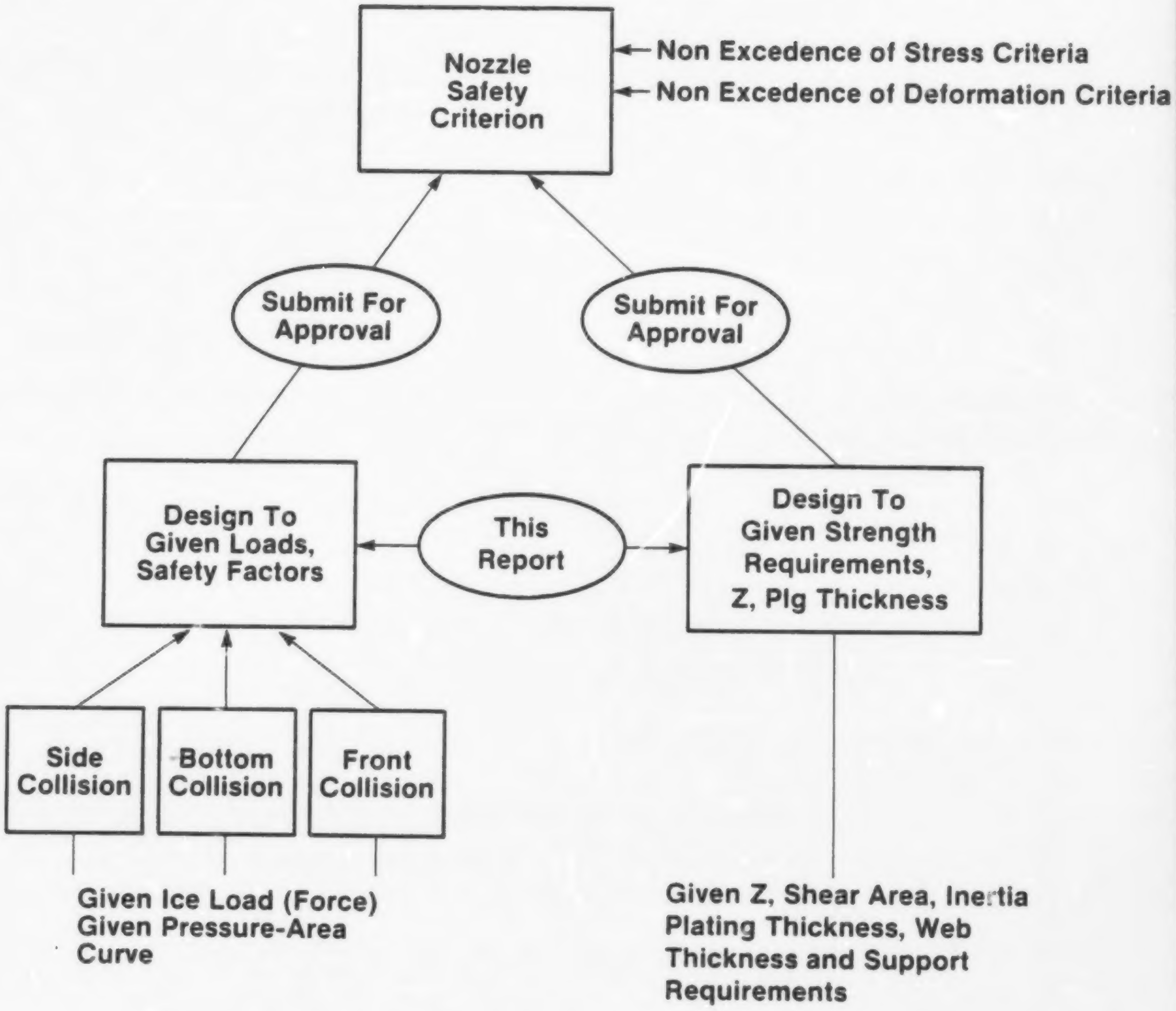
Global and local requirements are illustrated on Figure 10.2.

10.3 Designing To Minimum Force

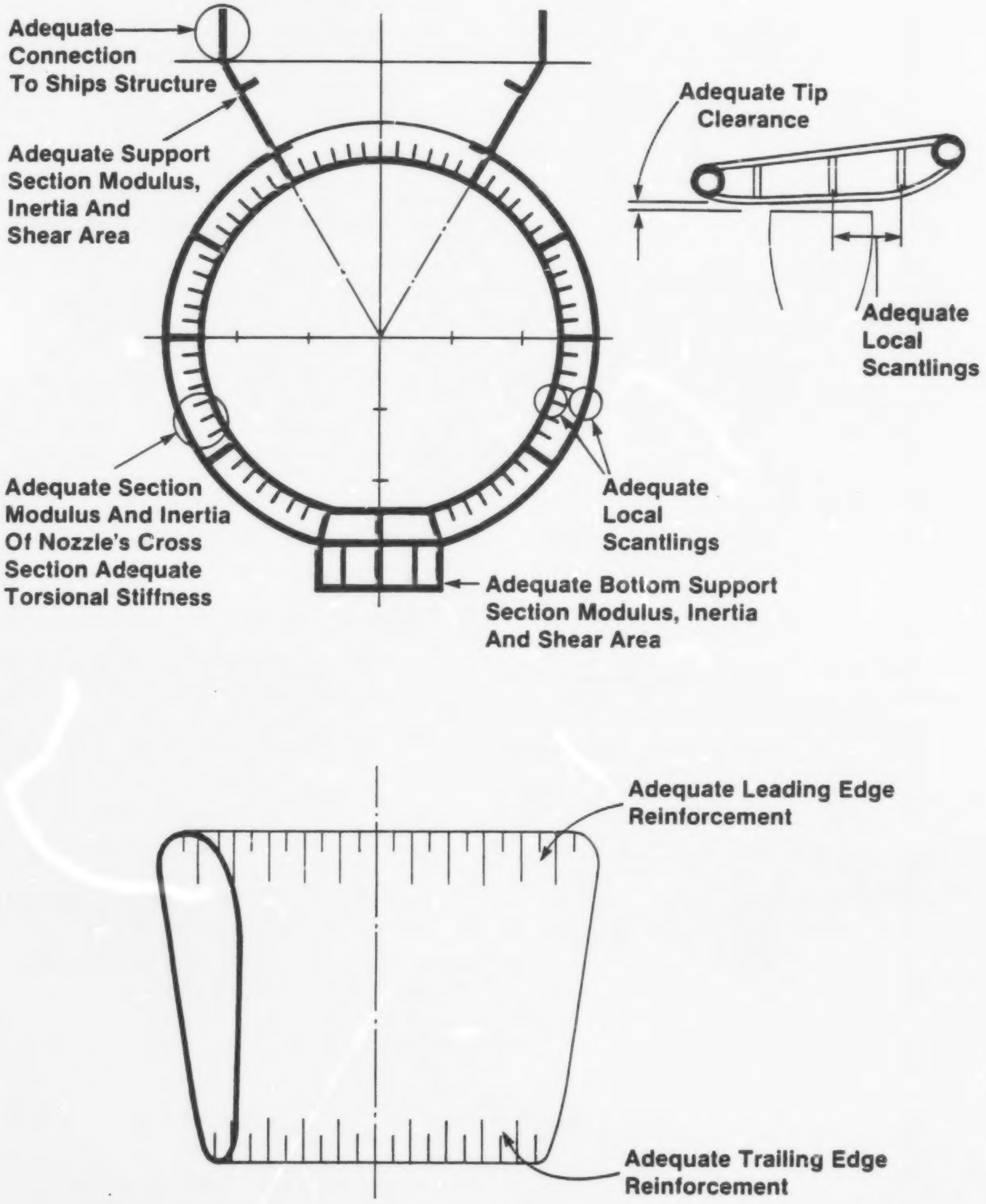
The radial ice force to be applied in the calculations of the nozzle's strength is a function of:

Ship Displacement: As the mass of the ship is responsible for the load generation.

Ship Horsepower: As higher horsepower gives higher velocity of impact which may lead to an increase of ice force.


Nozzle Safety Criterion
Non Excedence of Stress Criteria
Non Excedence of Deformation Criteria
Submit For Approval
Submit For Approval
Design To Given Loads, Safety Factors
This Report
Design To Given Strength Requirements, Z, Plg Thickness
Side Collision
Bottom Collision
Front Collision
Given Ice Load (Force)
Given Pressure-Area Curve
Given Z, Shear Area, Inertia
Plating Thickness, Web Thickness and Support Requirements

CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Approaches To Nozzle Safety
		FIGURE No. 10.1


Adequate Connection To Ships Structure
Adequate Support Section Modulus, Inertia And Shear Area
Adequate Tip Clearance
Adequate Local Scantlings
Adequate Section Modulus And Inertia Of Nozzle's Cross Section Adequate Torsional Stiffness
Adequate Local Scantlings
Adequate Bottom Support Section Modulus, Inertia And Shear Area
Adequate Leading Edge Reinforcement
Adequate Trailing Edge Reinforcement

CANADIAN MARINE DRILLING LIMITED

Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: **Global And Local Strength Requirements**

FIGURE No. 10.2

Nozzle Diameter: As a larger diameter gives higher contact area, and consequently higher ice loads.

Nozzle Location: As the ship response to a nozzle generated ice load for a twin shaft ship is different from a single shaft ship. The hull protects the nozzle to a greater or lesser degree depending upon nozzle location.

Ice Strength: The stronger the ice, the higher the ice induced load.

From the viewpoint of interaction, the kinetic energy of the ship can be chosen as a governing variable. However, since the velocity of the ship cannot be regulated at this time, ship horsepower can be used for the regulatory purposes. If we correlate ships velocity with its horsepower through the Admiralty Formula, ie.

$HP = (\Delta^{2/3} V^{3})/C$, then the kinetic energy of the ship can be approximated by:

$$K\,E \approx C\,(\Delta\ HP)^{\beta}$$

Further, if the penetration into the ice and consequently the ice force is proportional to the kinetic energy of the ship, then we can write:

$$F_{ICE} \approx C(\Delta HP)^{\beta}$$

Where β is an exponent determined experimentally.

It is impossible at this time to quantify the influence of diameter of the nozzle on the magnitude of the ice impact force. Intuitively, it is felt that the larger the diameter, the larger the impact force should be. If we use the analogy with the ship, the relationship is not a linear one. As diameter is strongly correlated with horsepower, we will relate it with the force through the already suggested function.

A centrally located nozzle generates higher loads than the wing located one. However, such a nozzle is better protected, ie. less exposed to ice than the wing one. It is not possible to establish an exact correlation between wing/centreline location and the severity and frequency of ice encounters. Canmar's experience with the ice loads on the propellers suggests that the wing located propeller/nozzle systems will experience higher loads than those located centrally. Consequently, a correction factor K_1 seems appropriate to take the nozzle location into account:

$$F_{ICE} = K_1(\Delta HP)^{\beta}$$

The ice induced force varies with the strength of ice σ according to the relationship:

$$F_{ICE} \alpha C \sigma^{\zeta}$$

where ζ is an exponent determined experimentally.

Since it is not possible to define precisely the value of the crushing strength of ice to be used, a concept of ice class can be used in lieu of σ. Intuitively, σ for class 10 corresponds to the heavy multi-year ice, while σ for ice class 2 may denote the strength of first year ice only.

Thus we arrive at:

$$F_{ice} \sim K_1 * K_2 * (\Delta HP)^{\beta}$$

Where K_2 is the correction for ice strength.

Based on the successful experience with the already existing nozzle designs, the following are the tentative values, subject to future full scale calibrations:

$K_1 = 1$ for the single shaft ships

$K_1 = 1.2$ for the twin shaft ships

If megawatts are used in the above formula, then: $K_1 = 1.04$ for single shaft ships; $K_1 = 1.25$ for twin shaft ships.

Using the existing nozzles as the guideline, we obtain the following values for the coefficients:

$K_2 = 100 + 60 *$ Ice Class

$\beta = 0.137$

The complete formulation now has the following form:

$$F_{ICE} = K_1 * (100 + 60 * \text{Ice Class}) * (\Delta \times HP)^{.137}$$

Where:

F_{ICE} is the design ice force expressed in tonnes.

K_1 is the nozzle location coefficient.

Ice Class is the ASPPR designated ice class.

Δ is ship displacement expressed in thousands of tonnes.

HP is the maximum continuous horsepower expressed in thousands of HP.

Values of K_2 are:

Ice Class	2	4	6	8	10
K_2	220	340	460	580	700

Examples of the F_{ICE} for the different Δ, HP and ice classes are given below:

ICE CLASS 2

	Δ				
HP	2,000	4,000	10,000	20,000	30,000
5,000	301	332	376	413	437
10,000	332	365	413	454	480
15,000	350	385	437	481	508
20,000	365	401	455	500	528

ICE CLASS 10

	Δ			
HP	30,000	60,000	90,000	300,000
30,000	1,777	1,955	2,066	2,437
60,000	1,955	2,150	2,272	2,680
90,000	2,066	2,272	2,402	2,833

For the wing nozzles, the above values should be multiplied by 1.2.

A comparison of the calculated F_{ICE} with the actual and future nozzle ddesigns is as follows:

SHIP	CALCULATED F_{ICE} USING ABOVE FORMULA TONNES	CALCULATED STRENGTH TONNES
Canmar Kigoriak	536 as Ice Class 3	1427
	1350 as Ice Class 10	1427
Robert Lemeur	566 as Ice Class 3	1000
Supplier 1 and 2	386	387
Supplier 7	355	189
Arctic	518	350 (Excluding Bottom Support)
Arctic	518	622 (Including Bottom Support)

Two more variables have to be set before the definition of the force is completed:

- direction of force application, and
- pressure/area distribution (load "spread")

Regarding the direction of force application, two conclusions can be drawn from the work done until now:

- The analytical model shows that the maximum bending moment is generated when the force is applied near the side segment of the nozzle ($\alpha = 105°$).

- ICESIM runs (6, 7, 8) indicate that the maximum radial force occurs when the force is applied 30° below the horizontal. The trend however, is not a strong one and can easily be changed for the single screw application.

Consequently, it is recommended that the radial ice force should be applied in the direction producing the maximum bending moment in the ring. This direction is given in Table 8.7 and for foundation half angle $\theta = 15°$ it is 105°.

In terms of the pressure/area distribution, some acceptable pressure/area curve.

Since the duration of ice nozzle interaction is in seconds (see ICESIM graphs) and the natural frequency of the nozzle ring is:

$$f > 50 \quad [\mathrm{Hz}]$$

It is reasonable to treat the ice induced force as a static one.

10.4 Designing To Scantlings

Global Scantlings:

The formula derived in paragraph 8.10 can be transformed to yield the minimum required section modulus:

$$SM_{min} = (K.F_{ice} \text{ x } R \text{ x } 1.04 \text{ x } (0.645-\theta/213)/\sigma_y$$

Where R is the effective radius of the nozzle ($R = R_o$ + 1/2 profile thickness).

θ is foundation 1/2 angle, in degrees.

F_{ice} is the ice force derived in the preceeding section.

K is the safety factor, tentatively suggested as 1.

σ_y is the yield strength of the nozzle plating material.

This formula assumes no yielding due to the global bending of the nozzle ring.

In addition, adequate inertia of the ring's section must be provided in order to assure ring deformations less than the propeller tip clearance. This is done by suitably transforming the formulation for ring's deflection given in paragraph 8.4:

$$0.01 \text{ x } R_o > FR^3/EI\ C_{\delta N}, \text{ from which}$$

$$I_{min} > K \text{ x } 22.8 \text{ x } F_{ice} \text{ x } R^3/R_oE$$

K being a safety factor, tentatively set at 1.

All units must be consistant.

Further, shear area in the radial direction X-X (web area plus end plating) should not be less than:

$$A_{shear} = (k \times .9\ F_{ice})/\tau$$

Where .9 is the shear force coefficient from Table 8.7. k is the safety facto. tentatively set at 1.0.

In order to avoid excessive penalties due to large unsupported flanges, and to assure large torsional rigidity of the nozzle, the number of ring webs should not be less than 2 per nozzle, up to 3.5 m long and 3 for nozzles of longer than 3.5 m and shorter than 5 m.

Local Scantlings:

The outer plating and supporting stiffeners of the nozzle should be calculated using the pressures for the sterns of icegoing ships, multiplied by a safety factor:

$$P_{NOZZLE} = K * P_{STERN}$$

Where K is tentatively set at 1.5. The area of application of this load should be:

$$A_{ICE} = (F_{ICE})/(P_{NOZZLE})$$

and should be distributed in a uniform strip extending the full length of the nozzle.

Foundation Support:

The nozzle should be attached at the top and bottom to the stern structure.

All ring webs should be attached to solid floors in the stern's structure.

A foundation angle of less than 30° is not recommended for ships of ice class higher than 4.

The stiffness of the head box and its connection to the nozzle are an important consideration in the overall deformations of the nozzle. Until an investigation of the foundation response to the ice loads is made, no specific recommendation can be offered.

In order to ensure the adequate shear area of the connection of the nozzle and foundation, the following observations can be made:

1. The axial loads are less than 1/2 of the radial loads.

2. Axial loads shear force coefficient is constant and equal to 1/2.

3. The shear area for axial load is a very important component of the structural integrity of the nozzle, as lack of it may result in the complete detachment of the nozzle from its support. Consequently, the safety factors used in the determination of the longitudinal shear area should be high.

Setting F_{ICE} axial ≅ 1/2 F_{ICE} radial, the following expression is obtained:

Total shear area in the longitudinal (axial) direction (for both upper and lower foundations) should not be less than:

$$(A_{shear})\text{ axial} > K \times 1/2\, F_{ICE}\text{ radial}/\tau$$

If we choose the safety factor as 2, then:

$$(A_{shear})\text{ axial} > F_{ICE}/\tau$$

The total longitudinal area of the attachment of nozzle to the foundation (both upper and lower) should not be less than the ice force as defined above divided by the shear strength of the material. If possible, this area should be distributed equally between the upper and lower foundations.

Webs and girders:

All webs and girders in the nozzle ring should be strengthened against buckling.

10.5 Practical Design Recommendations

The potential benefits of fitting nozzles on icebreaking ships are:

- Lowering the minimum power requirements due to thrust augmentation provided by the nozzle; and
- lowering the strength requirements for the propulsion train due to propeller protection provided by the nozzle.

Provided the strength requirements are fulfilled.

As the nozzles of icebreaking ships will operate for a prolonged time in heavy overload conditions in non-uniform water flow (ice blocks interference) it is recommended that:

1. Cavitation margins are increased on the propeller design.

2. Particular care it taken in ensuring proper water inflow into the nozzle ie. streamlining of appendages fore and aft of the nozzle.

3. The inside and outside of the nozzle is covered with the abrasion resistant coating.

4. All welds are ground smooth inside of the nozzles ring.

5. The vibration characteristics of the nozzle's ring and attachment are checked and their incompatibility with propeller induced pressure fluctuations is assured.

6. The inner plating thickness in way of the propeller blades should not be less than the thickness of the outer plating.

   This requirement comes from the fact that pieces of ice milled by the propeller are then squashed by it against the inner plating of the nozzle.

7. The leading and trailing edges of the nozzle should be reinforced to take high speed impacts from ice blocks.

11. PLANNING OF FUTURE FULL SCALE R & D PROGRAM TO VALIDATE SUGGESTED REQUIREMENTS

The most important aspect of the suggested requirements is knowledge of the load, that is:

- Magnitude,
- Direction,
- Point of Application,
- Pressure/Area Relationship,
- Duration.

If the load is known, an accurate assessment of the nozzle's structural response can be made. The degree of accuracy is dependent only on the amount of effort one wishes to employ in modelling the nozzles structural response.

It was shown, that the force itself depends on many parameters, such as:

- ship displacement,
- horsepower,
- speed of impact,
- nozzle geometry and location,
- ice conditions,
- operating scenario.

In order to validate the proposed relationships and design criteria, the following R & D program philosophy is suggested:

1. For one existing ship, gather statistical information on nozzle stresses.
2. Fully instrument a newly built ship. Execute a series of full scale trials in order to calibrate the suggested formulations.
3. Based on the above, propose concrete numerical values for the general formulations derived in this report.

To obtain the necessary information from the newly built ship, the following program is recommended:

1. To develop an FEM model of the nozzle structure and to investigate the most suitable gauge locations.

2. To instrument bottom and top foundations of the nozzle with strain gauges. Strain gauges can be so arranged as to permit an accurate assessment of force magnitude, direction and location to be deduced from the gauge readings.

3. To calibrate the gauges with a series of controlled loads while the ship is in drydock. Loads can be applied by means of hydraulic jacks and/or a calibrated pendulum.

4. To establish load response transfer function, preferably by programming these into a high speed computer data processing system. Load predictions from the recorded strain gauge readings will then be possible.

5. To install 2 accelerometers at the stern.

6. To collect the data during a part of an operating season.

7. To analyze the data from strain gauges and accelerometers.

8. To compare the data with the recommendations and to suggest calibration factors, changes and new issues, if any.

9. To report on items 1 to 6.

As strain gauging of an existing vessel is extremely difficult and costly, it is suggested that the above programs would best suit new ship construction. The strain gauging and instrumentation of the nozzle would be implemented at the design stage and follow through to the completion of construction. To ensure that the chosen vessel can operate in a severe enough environment to develop high ice loading in such features as multiyear ridges the ice class should be at least Class 4.

12. CONCLUSIONS AND RECOMMENDATIONS

Existing nozzles fitted on icegoing vessels perform well.

Methods presented in this report will enable structures to be extrapolated from small size, low ice class nozzle to large size, high ice class nozzle structures.

12.1 Conclusions

1. The nozzle strength increases with its diameter. The rate of growth depends on the plating thickness and geometry.
2. The ability of the nozzle to sustain ice impact loads is improved by increasing the nozzle section chord length and/or chord thickness.
3. The governing stresses are compressive stresses due to bending and hoop force. The inner plating will yield in compression, before the outer plating if both are of equal thickness.
4. Side loads cause higher stresses than bottom loads or axial loads of the same magnitude.
5. The largest stresses occur near the foundation support.
6. The analytical model with rigid foundations predicts the stresses well, except for the area near the foundations, where in reality, lower stresses occur due to the foundation flexibility.
7. Deformations of the nozzle ring are not significant factors in strength calculations for infinitely stiff foundations. For very weak foundations however, they are decisive.
8. Based on the analysis performed in chapter 8, nozzles of 2 m diameter can withstand radial loads of approximately 400 tonnes. Nozzles of 8 m diameter can withstand radial loads of 3,000 tonnes, for the foundation angle $\Theta = 15°$.
9. ICESIM model has been proven to be useful in predicting the absolute results, the general dependencies of ice load on the ship displacement, number of shafts and ice strength purposes without full scale calibration.

10. If full scale test results prove that loads are higher than those recommended in the proposed roles, the differences can be easily accommodated by the increase of the foundation angle, thickness and profile thickness and/or length. For example, using nozzle 4C with plating 0.050 m and $\Theta = 60°$, the strength of the nozzle becomes 5850 tonnes.

12.2 Recommendations

The recommendations arising from this report fall into two categories:

1. Those concerning use of the derived formulations.

2. New studies to calibrate the formulations in the present project.

Based on the present study the recommended procedure for calculating any nozzle's strength requirements is given below:

The inputs, assumed to be available, are:

- Ship displacement and horsepower
- ASPPR ice class
- Nozzle diameter and section profile
- Upper foundation angle Θ
- Nozzle location (centre/wing).

The steps for calculating the nozzle strength are as follows:

1. Calculate ice force, using the formula:
   $F_{ICE} = K_1 * K_2 * (\Delta\ HP)\beta$

2. Calculate nozzle testing thickness using the formula for ice pressure:

   $$P_{NOZZLE} = 1.5\ P_{STERN}$$

3. Calculate nozzle profile section modulus using simplified (rectangular box) profile.

4. Calculate nozzle strength using the formula:

$$F_{MAX} = Z * \sigma_y/R * 1.04\ (.645 - \Theta/213)$$

5. Compare F_{MAX} with F_{ICE}. If $F_{MAX} < F_{ICE}$, increase any of (or combination of):

- Foundation Angle
- Plating Thickness
- Profile Thickness
- Strength of Material

6. Check shear area in radial and longitudinal directions as per 10.4.

7. Check other requirements, including:

   Bottom Attachment
   Moment of Inertia
   VR of Webs

   Detailed list of the requirements is given in Chapter 10 of volume 1 of the main report.

8. If optimization of the nozzle structure is contemplated, use the programs developed for detailed evaluation of the stresses in the nozzle ring.

In order to calibrate and improve the formulations in this report the following steps are recommended:

1. A study of the influence of the structural characteristics of nozzle top and bottom support on the nozzle strength.

2. A study of varying the section properties around the circumference (especially at the foundation) to match the stress distribution should be made.

3. A study of the influence of pressure/area distribution on the magnitude of ice impact forces.

4. Limited scope of measurements on an existing nozzle to gather statistical data on nozzle stresses.

5. Full instrumentation of a newly built nozzle followed by full scale testing in ice.

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STUDY OF STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

APPENDICES

PREPARED FOR
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BY: V. LASKOW
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CANADIAN MARINE DRILLING LTD.
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17. Abstract

The objective of the project was to define and study in detail the factors and design criteria affecting ice-going propeller nozzle strength requirements and to formulate general analytical expressions which, when calibrated, could be used for design and regulatory purposes.

The major effort in the study of nozzle strength was the development of an analytical model. Bottom, side and axial loading cases were investigated for a ring structure. Bending and torsional moments, shear and tangential forces and deflections were calculated around the ring. In addition the foundation reactions and the effect of load spread were determined. The applicability of these results to a three-dimensional case was confirmed by finite element modelling.

The study concluded by suggesting requirements for regulatory body consideration and by proposing a full-scale test program.

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17. Résumé

L'objectif de ce programme était de définir et d'approfondir les facteurs et les critères de calcul concernant la résistance à donner aux tuyères protégeant les hélices des navires naviguant dans les glaces, et d'établir des équations d'application générale visant à faciliter les fonctions de calcul et de réglementation.

L'objectif principal de la présente recherche a été la formulation d'un modèle tenant compte des régimes de charge s'exerçant dans les trois axes d'une structure annulaire. Les moments de flexion et de torsion, les efforts de cisaillement et les forces tangentielles, ainsi que les déformations correspondantes ont été calculés. En outre, les réactions dans le carlingage ainsi que l'effet de la répartition des charges ont été déterminés. Enfin, l'applicabilité du modèle formulé à une structure tridimensionnelle a été confirmée par la méthode des éléments finis.

Le rapport termine par des suggestions concernant les critères de réglementation et en préconisant un programme d'essais en vraie grandeur.

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APPENDIX A

COMPUTERIZED ANALYTICAL MODEL DOCUMENTATION

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1. INTRODUCTION

The theory of the structural response of circular arches to external loads is well developed. Reference 8.1 gives the most general formulations of the response of such arches. Due to the complexity of the formulations, computer programs were developed to handle parametric variations of all of the input variables. Further, a thorough check of handbook formulations was performed using the analytical model, as derived in Chapter 8. These checks were found to be completely satisfactory. Therefore, a decision was made to use the computerized model for an in depth study of the structural response of circular arches to the applied static loads.

Two load cases were investigated in detail:

radial, and axial.

Either of them can be treated as a point load, or a distributed load over a prescribed area. The load can be applied anywhere on the ring.

The nozzle is represented as a curved beam, having the following properties:

- Foundation Angle
- Radius
- Stiffness EI
- Shear Stiffness GA
- Torsional Stiffness
- Stress Distribution Factor

The foundation stiffness is considered infinite in all of the programs and analytical formulations.

Program documentation is provided, below, followed by the program listing and sample outputs.

2. STRENGTH OF NOZZLE PROGRAM DOCUMENTATION

2.1 Computer Program Documentation

2.2 Introduction

As part of the study of the strength requirements for nozzles of ice transiting ships, computer programs were developed with the objective of performing a parametric study of the effect of a unit load and nozzle foundation angles on the bending moments, shear forces and normal forces distributions.

User instructions are supplied, and the required data is fully explained. The user should be able to operate the Hewlett-Packard 9845B or 9845C computer using HP extended BASIC.

The equations and assumptions used in the program can be referred to in "Formulas for Stress and Strain", Table 18, load case 5C: Concentrated horizontal load for circular arches.

2.3 Program Documentation "NOZ-5:F8"

Definitions and Symbols:

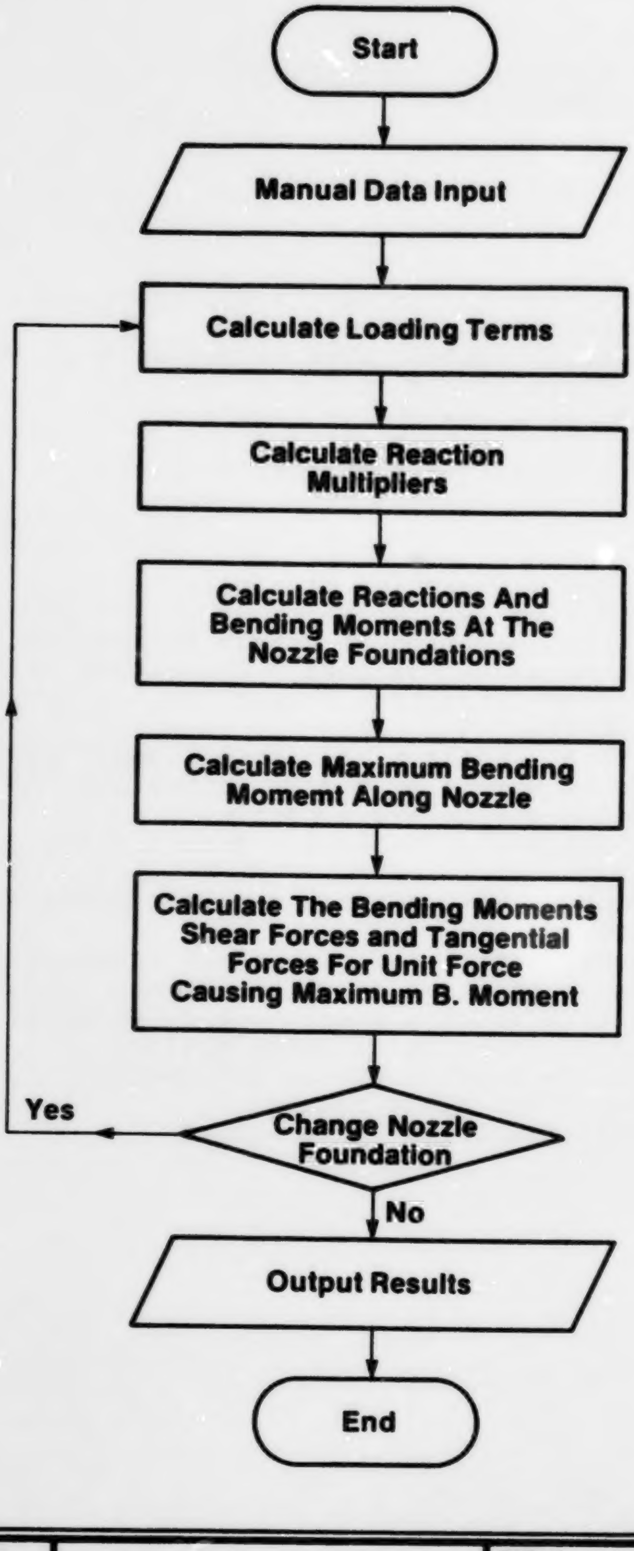
Input

1. Nozzle foundation half angle (degrees) = Ted (Z)
2. Nozzle radius (metres) = R
3. Number of concentrated radial forces = Nu
4. Concentrated radial force = F(I)
5. Angle of radial force (degrees) = Fd(I)
6. Axial stress deformation factor = Al
7. Transverse shear deformation factor = Be

Output

8. Horizontal reaction at nozzle foundation 'A' = Ha
9. Vertical reaction at nozzle foundation 'A' = Va
10. Bending moment at nozzle foundation 'A' = Ma
11. Horizontal reaction at nozzle foundation 'B' = Hb
12. Vertical reaction at nozzle foundation 'B' = Vb
13. Bending moment at nozzle foundation 'B' = Mb
14. Bending moment along nozzle = Bm
15. Maximum positive bending moment along nozzle = Bm(max)
16. Maximum negative bending moment along nozzle = Bm(min)
17. Angular position along nozzle (degrees) = X
18. Angular position at which maximum positive bending moment occurs (degrees) = X(max)
19. Angular position as which maximum negative bending occurs (degrees) = X(min)
20. Shear force along nozzle = Sf
21. Tangential force along nozzle = Tf

NOZ - 5:F8


Start
Manual Data Input
Calculate Loading Terms
Calculate Reaction Multipliers
Calculate Reactions And Bending Moments At The Nozzle Foundations
Calculate Maximum Bending Momemt Along Nozzle
Calculate The Bending Moments Shear Forces and Tangential Forces For Unit Force Causing Maximum B. Moment
Change Nozzle Foundation
Yes
No
Output Results
End

CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Strength Of Nozzle Program Documentation Flow Chart FIGURE No. A-1

2.4 User Instructions
"NOZ-5:F8"

This program has been designed for use in the Hewlett Packard HP 9845B or 9845C computer. It is written in HP extended Basic. Detailed information is available in the HP 9845 Operating and Procedures Manual.

Definitions:

Type:	Means to enter from the Keyboard the information exactly as shown.
Press:	Means to use the stated special function key.
Cont:	Means to press the Cont (continue) key.

Program execution steps:

Step 1

Place the program diskette into the disc drive "F8" and turn the computer on.

Step 2

Loading the program into the computer memory.

i. Type: GET "NOZ-5:F8"
Press: EXECUTE
When the square mark on the right hand side of the screen goes out, press: RUN
Once the program is running, the instructions will appear on the screen to prompt you to enter the input data. The screen instructions are shown below in capital letter and between quotation marks.

Step 3

Input Data (Refer to definition of nozzle foundations and angles)

i. "ENTER: NOZZLE RADIUS (METRES)"
Type in the nozzle radius and CONT. If the nozzle radius is not known, type "1" and CONT.

ii. "ENTER: NUMBER OF NOZZLE FOUNDATION ANGLES (MAX 5)"
Type in the number of different nozzle foundation angles (a maximum of 5) for which you wish to do a parametric study and CONT.

iii. "ANGLE NO. __ ENTER: NOZZLE FOUNDATION HALF-ANGLE (DEGREES)"
Type in the nozzle foundation half-angle. This is repeated for the number of nozzle foundation half-angles specified in (2) and CONT.

iv "ENTER: NUMBER OF UNIT CONCENTRATED RADIAL FORCES (MAX 12)"
Type in the number of different unit concentrated forces (a maximum of 12) for which you wish to do a parametric study and CONT.

v "FORCE NO. __ ENTER: CONCENTRATED RADIAL FORCE (UNIT FORCE)"
Type: 1 (for unit force) and CONT. unless a specified value of force is given.

vi "FORCE NO. __ ENTER: ANGLE OF RADIAL FORCE (DEGREES)"
Type in the angle of radial force and CONT. (5) and (6) are repeated for the number of unit concentrated radial forces specified in (4).

vii "ENTER: THE AXIAL STRESS DEFORMATION FACTOR"
Type "0" and CONT. if the actual value of the axial stress deformation factor is not known.

viii "ENTER: THE TRANSVERSE SHEAR DEFORMATION FACTOR"
Type "0" and CONT. if the actual value of the transverse shear deformation factor is not known.

ix "PERFORM PARAMETRIC STUDY OF EFFECT OF NOZZLE FOUNDATION ANGLE"
Type "Y" and CONT if there is more than one nozzle angle specified in (2). Type "N" and CONT if there is only one nozzle angle specified in (2).

2.5 DISTRIBUTED RADIAL LOAD CASE "NOZ-5A:F8"
SIMILAR TO INSTRUCTIONS FOR "NOZ-5:T5" EXCEPT AS SHOWN

Step 1

Input Data

i "ENTER: NOZZLE RADIUS (METRES)"
Type in the nozzle radius and CONT. If the nozzle radius is not known, type "1" and CONT.

ii "ENTER: NOZZLE FOUNDATION HALF-ANGLE (DEGREES)"
Type in the nozzle foundation half-angle in degrees.

iii "ENTER: NUMBER OF DISTRIBUTED RADIAL FORCES (MAX 12)"
Type in the number of distributed radial forces (a maximum of 12) acting along nozzle.

iv "FORCE NO __ ENTER: DISTRIBUTED RADIAL FORCE (UNIT FORCE)"
Type: 1 (for unit force) and CONT. unless a specified value of force is given.

v "FORCE NO __ ENTER: ANGLE OF RADIAL FORCE (DEGREES)"
Type in the angle of radial force and CONT (d) and (e) are repeated for the number of distributed radial forces entered in (c).

vi "ENTER: THE AXIAL STRESS DEFORMATION FACTOR"
Type "0" and CONT. if the actual value of the axial stress deformation factor is not known.

vii "ENTER: THE TRANSVERSE SHEAR DEFORMATION FACTOR"
Type "0" and CONT. if the actual value of the transverse shear deformation factor is not known.

2.6 User Instructions For "Noz-5B:F8" - Axial Load

Input Data

i "ENTER: NOZZLE RADIUS (METRES)"
Type in the nozzle radius and CONT. If the nozzle radius is not known, type "1" and CONT.

ii "ENTER: NOZZLE FOUNDATION HALF-ANGLE (DEGREES)"
Type in the nozzle foundation half-angle in degrees.

iii "ENTER: ANGLE FROM LEFT AND TO POSITION OF LOADING (DEGREES)"
Type in angle from left end of the nozzle foundation to the position of load application in degrees.

iv "ENTER: VALUE OF Be (Be = EI/GK)"
Type in the value of Be (dimensionless)
Be = EI/GK, where
E = modulus of elastic
I = area moment of inertia about the bending units
G = modulus of rigidity
K = torsional stiffness constant of the cross section.

v "ENTER: APPLIED LOAD NORMAL TO PLANE OF CURVATURE"
Type in the applied load normal to plane of circulature and CONT.
If unit load is required, type "1" and CONT.

3. PROGRAM NOZ-5:F8 LISTING

```
10   ! PROGRAM TO PERFORM PARAMETRIC CALCULATIONS OF NOZZLE STRENGTH FOR
20   ! UNIT CONCENTRATED RADIAL LOADS.
30   ! PROGRAM SAVED AS A DATA FILE AND IS TO BE RUN ON HP9845B OR HP9845C
40   ! PROGRAM "NOZ-5:F8" UPDATED 06/09/84
50   ! REFER TO PROGRAM DOCUMENTATION FOR DEFINITIONS AND EQUATIONS
60   ! REFERENCE :"FORMULAS FOR STRESS AND STRAIN",TABLE 18,CASE 5c
70   !
80   !   DECLARE VARIABLES
90   !
100   OPTION BASE 1
110  !
120   INTEGER J,I,K,Z,N1,Nu,C1
130   INTEGER Ted(5),Fd(12),Xmaxd(5,12),Xmind(5,12),X1(5,12)
140   INTEGER C_max(5),C_min(5)
150   REAL Te(5),S(5),C(5)
160   REAL Phix(361)
170   REAL X,Xd,Xb,R,A1,Be
180   REAL F1(12),F(12),N(12),E(12)
190   REAL Lfh(5,12),Lfv(5,12),Lfm(5,12)
200   REAL Bhh(5),Bhv(5),Bvh(5),Bhm(5),Bmh(5),Bvv(5),Bvm(5),Bmv(5),Bmm(5)
210   REAL Ha(5,12),Va(5,12),Ma(5,12),Hb(5,12),Vb(5,12),Mb(5,12)
220   REAL Mx(5,12,361),Ms(12,361)
230   REAL Sums2(5,361),Sbmax(5),Sbmin(5),Sxmax(5),Sxmin(5)
240   REAL Sf(5,12,25),Tf(5,12,25)
250   REAL A(3,3),B(3,3),L(3),G(3),Bmax(5,12),Bmin(5,12),B1(5,12)
260   REAL Xmax(5,12),Xmin(5,12)
270   REAL Maxi1(5),Mini1(5)
280  !
290 Main: !
300    GOSUB Input_data
310    GOSUB Angles
320    GOSUB Load_terms
330    GOSUB Multipliers
340    GOSUB Fixed_reactions
350    GOSUB Bending_moments
360    GOSUB Parametric1
370    GOSUB Moments_forces
380    GOSUB Parametric2
390    GOSUB Print_table1
400    STOP
410    END
420  ! !
430 Input_data: !
440    INPUT "ENTER: NOZZLE RADIUS (METRES)",R
450    INPUT "ENTER: NUMBER OF NOZZLE FOUNDATION ANGLES (MAX.5)",N1
460    FOR Z=1 TO N1
470      DISP "ANGLE NO.";Z;
480      INPUT "    ENTER:NOZZLE FOUNDATION HALF-ANGLE (DEGREES)",Ted(Z)
490    NEXT Z
500    INPUT "ENTER: NUMBER OF UNIT CONCENTRATED RADIAL FORCES (MAX.12)",Nu
510    FOR I=1 TO Nu
520      DISP "FORCE NO.";I;
530      INPUT "   ENTER: CONCENTRATED RADIAL FORCE (UNIT FORCE)",F(I)
540      DISP "FORCE NO.";I;
550      INPUT "   ENTER: ANGLE OF RADIAL FORCE (DEGREES)",Fd(I)
560    NEXT I
570    INPUT " ENTER: THE AXIAL STRESS DEFORMATION FACTOR",A1
580    INPUT " ENTER: THE TRANSVERSE SHEAR DEFORMATION FACTOR",Be
590    INPUT "PERFORM PARAMETRIC STUDY OF EFFECT OF NOZZLE FOUNDATION ANGLE(Y OR
N)?",Q$
600    RETURN
610  !
620 Angles: !
630  ! CALCULATE THE SINES AND COSINES OF THE NOZZLE FOUNDATION HALF-ANGLES
640  ! AND THE RADIAL FORCES ANGLES
650    FOR Z=1 TO N1
```

CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:

"NOZ-5 : F8"
PROGRAM LISTING

FIGURE No. A9

```
660      Te(Z)=Ted(Z)*PI/180
670      S(Z)=SIN(Te(Z))
680      C(Z)=COS(Te(Z))
690    NEXT Z
700    FOR I=1 TO Nu
710      F1(I)=Fd(I)*PI/180
720      N(I)=SIN(F1(I))
730      E(I)=COS(F1(I))
740    NEXT I
750    RETURN
760   !
770 Load_terms: !
780   ! CALCULATE THE LOADING TERMS:Lfh(Z,I),Lfv(Z,I),Lfm(Z,I)
790    FOR Z=1 TO N1
800      FOR I=1 TO Nu
810         Lfh(Z,I)=F(I)*(E(I)/2*(1+C(Z)^2)-C(Z)-S(Z)*C(Z)*N(I)/2+N(I)/2*(Te(Z)+F
1(I))+(A1+Be)*(N(I)/2)*(Te(Z)+F1(I))+(A1-Be)*(S(Z)/2)*(S(Z)*E(I)+C(Z)*N(I)))
820         Lfv(Z,I)=F(I)*(E(I)/2*(Te(Z)+F1(I))+S(Z)-1.5*C(Z)*(S(Z)*E(I)+C(Z)*N(I)
)+N(I)+(A1+Be)*(E(I)/2)*(Te(Z)+F1(I))-(A1-Be)*(C(Z)/2)*(S(Z)*E(I)+C(Z)*N(I)))
830         Lfm(Z,I)=F(I)*(1-C(Z)*E(I)+S(Z)*N(I))
840       NEXT I
850    NEXT Z
860    RETURN
870   !
880 Multipliers: !
890   ! CALCULATE THE REACTION MULTIPLIERS:Bhh(Z),BhV(Z),Bvh(Z),Bhm(Z),Bmh(Z),Bvv
(Z),Bvm(Z),Bmv(Z),Bmm(Z)
900    FOR Z=1 TO N1
910       Bhh(Z)=Te(Z)+2*Te(Z)*C(Z)^2-3*S(Z)*C(Z)+A1*(Te(Z)+S(Z)*C(Z))+Be*(Te(Z)-S
(Z)*C(Z))
920       Bhv(Z)=Bvh(Z)=2*S(Z)^2-2*Te(Z)*S(Z)*C(Z)
930       Bhm(Z)=Bmh(Z)=2*S(Z)-2*Te(Z)*C(Z)
940       Bvv(Z)=Te(Z)+2*Te(Z)*S(Z)^2-S(Z)*C(Z)+A1*(Te(Z)-S(Z)*C(Z))+Be*(Te(Z)+S(Z
)*C(Z))
950       Bvm(Z)=Bmv(Z)=2*Te(Z)*S(Z)
960       Bmm(Z)=2*Te(Z)
970    NEXT Z
980    RETURN
990   !
1000 Fixed_reactions:!
1010 ! CALCULATE THE REACTIONS AND BENDING MOMENT AT NOZZLE FOUNDATION "A"
1020 ! BY SOVLING THE THREE DEFORMATION EQUATIONS SIMULTANEOUSLY
1030   FOR Z=1 TO N1
1040     FOR I=1 TO Nu
1050       A(1,1)=Bhh(Z)
1060       A(1,2)=Bhv(Z)
1070       A(1,3)=Bhm(Z)
1080       A(2,1)=Bvh(Z)
1090       A(2,2)=Bvv(Z)
1100       A(2,3)=Bvm(Z)
1110       A(3,1)=Bmh(Z)
1120       A(3,2)=Bmv(Z)
1130       A(3,3)=Bmm(Z)
1140       L(1)=Lfh(Z,I)
1150       L(2)=Lfv(Z,I)
1160       L(3)=Lfm(Z,I)
1170       MAT B=INV(A)
1180       MAT G=B*L
1190       Ha(Z,I)=G(1)
1200       Va(Z,I)=G(2)
1210       Ma(Z,I)=G(3)*R
1220 ! CALCULATE THE REACTIONS AND BENDING MOMENT AT NOZZLE FOUNDATION "B"
1230       Hb(Z,I)=F(I)*SIN(F1(I))-Ha(Z,I)
1240       Vb(Z,I)=F(I)*COS(F1(I))-Va(Z,I)
1250       Xb=-Te(Z)
1260       Sx=SIN(F1(I)-Xb)
```

CANADIAN
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MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE:

"NOZ-5 : F8"
PROGRAM LISTING

FIGURE No. A10

```
1270        IF F1(I)-Xb<=0 THEN Sx=0
1280        Mb(Z,I)=-(Ma(Z,I)+Ha(Z,I)*R*(COS(Xb)-COS(Te(Z)))-Va(Z,I)*R*(SIN(Xb)-SI
N(Te(Z)))-F(I)*R*Sx)
1290 ! BENDING MOMENT AT NOZZLE FOUNDATION = -(BENDING MOMENT AT END OF NOZZLE)
1300        IF Fd(I)>Ted(Z) THEN Ha(Z,I)=Va(Z,I)=Ma(Z,I)=Hb(Z,I)=Vb(Z,I)=Mb(Z,I)=0
1310      NEXT I
1320    NEXT Z
1330    RETURN
1340 !
1350 Bending_moments:    !
1360        ! CALCULATE THE BENDING MOMENTS ALONG THE NOZZLE
1370        ! CALCULATE THE MAXIMUM POSITIVE AND NEGATIVE BENDING MOMENTS ON NOZZLE
1380    FOR Z=1 TO N1
1390      FOR I=1 TO Nu
1400        J=0
1410        FOR X=Te(Z) TO -Te(Z) STEP -PI/180
1420          J=J+1
1430          Phix(J)=X
1440          Sx=SIN(F1(I)-X)
1450          IF F1(I)-X<=0 THEN Sx=0
1460          Mx(Z,I,J)=Ma(Z,I)+Ha(Z,I)*R*(COS(X)-COS(Te(Z)))-Va(Z,I)*R*(SIN(X)-SI
N(Te(Z)))-F(I)*R*Sx
1470          IF Fd(I)>Ted(Z) THEN Mx(Z,I,J)=0
1480        NEXT X
1490      NEXT I
1500    NEXT Z
1510    RETURN
1520 !
1530 Parametric1:!
1540    ! PERFORM PARAMETRIC STUDY OF EFFECT OF RADIAL FORCE ANGLE
1550    ! CALCULATE THE MAXIMUM POSITIVE AND NEGATIVE BENDING MOMENTS ON NOZZLE
1560    FOR Z=1 TO N1
1570      FOR I=1 TO Nu
1580        Xmax(Z,I)=Te(Z)
1590        Xmin(Z,I)=Te(Z)
1600        Bmax(Z,I)=Mx(Z,I,1)
1610        Bmin(Z,I)=Mx(Z,I,1)
1620        FOR J=1 TO 361
1630          Bmax(Z,I)=MAX(Mx(Z,I,J),Bmax(Z,I))
1640          Bmin(Z,I)=MIN(Mx(Z,I,J),Bmin(Z,I))
1650          IF Mx(Z,I,J)=Bmax(Z,I) THEN Xmax(Z,I)=Te(Z)+(J-1)*-PI/180
1660          IF Mx(Z,I,J)=Bmin(Z,I) THEN Xmin(Z,I)=Te(Z)+(J-1)*-PI/180
1670          IF (Bmax(Z,I)<.00010) AND (Bmin(Z,I)>-.00010) THEN Xmax(Z,I)=Te(Z)
1680          IF (Bmax(Z,I)<.00010) AND (Bmin(Z,I)>-.00010) THEN Xmin(Z,I)=Te(Z)
1690          Xmaxd(Z,I)=Xmax(Z,I)*180/PI
1700          Xmind(Z,I)=Xmin(Z,I)*180/PI
1710        NEXT J
1720      NEXT I
1730      Maxi1(Z)=Bmax(Z,1)
1740      Mini1(Z)=Bmin(Z,1)
1750      FOR I=1 TO Nu
1760        Maxi1(Z)=MAX(Maxi1(Z),Bmax(Z,I))
1770        Mini1(Z)=MIN(Mini1(Z),Bmin(Z,I))
1780        IF Maxi1(Z)=Bmax(Z,I) THEN C_max(Z)=I
1790 '      IF Mini1(Z)=Bmin(Z,I) THEN C_min(Z)=I
1800      NEXT I
1810    NEXT Z
1820    RETURN
1830 !
1840 Moments_forces:!
1850 ! CALCULATE BENDING MOMENTS,SHEAR FORCES AND TANGENTIAL FORCES ALONG NOZZLE
1860    FOR Z=1 TO N1
1870      C1=C_max(Z)
1880      IF ABS(Mini1(Z))>Maxi1(Z) THEN C1=C_min(Z)
1890      J=0
1900      FOR X=Te(Z) TO -Te(Z) STEP -15*PI/180
```

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MEASUREMENT OF ICE PROPELLER
INTERACTION PARAMETERS

TITLE:
"NOZ-5 : F8"
PROGRAM LISTING

FIGURE No. A11

```
1910        Xd=X*180/PI
1920        J=J+1
1930        Phix(J)=X
1940        Sx=SIN(F1(C1)-X)
1950        Cx=COS(F1(C1)-X)
1960        IF F1(C1)-X<=0 THEN Sx=0
1970        IF F1(C1)-X<=0 THEN Cx=0
1980        Mx(Z,C1,J)=Ma(Z,C1)+Ha(Z,C1)*R*(COS(X)-COS(Te(Z)))-Va(Z,C1)*R*(SIN(X)-
SIN(Te(Z)))-F(C1)*R*Sx
1990        Sf(Z,C1,J)=-Ha(Z,C1)*SIN(X)-Va(Z,C1)*COS(X)+F(C1)*Cx
2000        Tf(Z,C1,J)=-(-Ha(Z,C1)*COS(X)+Va(Z,C1)*SIN(X)+F(C1)*Sx)
2010      NEXT X
2020    NEXT Z
2030    RETURN
2040  !
2050  Parametric2:    !
2060    ! PARAMETRIC STUDY OF EFFECT OF RADIAL FORCE ANGLE AND NOZZLE
2070    ! FOUNDATION ANGLE ON MAXIMUM BENDING MOMENT.
2080    FOR I=1 TO Nu
2090      FOR Z=1 TO N1
2100        B1(Z,I)=Bmax(Z,I)
2110        X1(Z,I)=Xmaxd(Z,I)
2120        IF ABS(Bmin(Z,I))>Bmax(Z,I) THEN B1(Z,I)=Bmin(Z,I)
2130        IF ABS(Bmin(Z,I))>Bmax(Z,I) THEN X1(Z,I)=Xmind(Z,I)
2140      NEXT Z
2150    NEXT I
2160    RETURN
2170    !
2180  Print_table1: !
2190    FOR Z=1 TO N1
2200      PRINT PAGE
2210      PRINT LIN(2)
2220      PRINT TAB(24);"************************************"
2230      PRINT TAB(24);"*";TAB(27);"CALCULATION OF NOZZLE STRENGTH";TAB(59);"*"
2240      PRINT TAB(24);"************************************"
2250      PRINT LIN(1);TAB(25);"UNIT CONCENTRATED RADIAL LOADS CASE"
2260      PRINT LIN(2);TAB(20);"NOZZLE FOUNDATION HALF-ANGLE (DEGREES)=";Ted(Z)
2270  !   PRINT TABLE OF REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS
2280      PRINT LIN(4);TAB(20);"REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATION
S"
2290      PRINT LIN(1);TAB(10);"Fd(I)";TAB(22);"Ha";TAB(32);"Va";TAB(42);"Ma";TAB(
52);"Hb";TAB(62);"Vb";TAB(72);"Mb"
2300      IMAGE 10X,DDD,5X,MD.DDD,5X,M.DDD,5X,M.DDD,5X,M.DDD,5X,M.DDD,5X,M.DDD
2310      FOR I=1 TO Nu
2320        PRINT USING 2300;Fd(I);Ha(Z,I);Va(Z,I);Ma(Z,I);Hb(Z,I);Vb(Z,I);Mb(Z,I)
2330      NEXT I
2340  !   PRINT TABLE LF MAXIMUM POSITIVE AND NEGATIVE BENDING MOMENTS
2350  !   FOR UNIT RADIAL FORCES APPLIED AT DIFFERENT ANGLES
2360      PRINT LIN(4);TAB(20);"EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS"
2370      PRINT LIN(1);TAB(18);"Fd(I)";TAB(29);"Bm(max)";TAB(41);"X(max)";TAB(53);
"Bm(min)";TAB(66);"X(min)"
2380      IMAGE 18X,DDD,7X,M.DDD,8X,MDDD,8X,M.DDD,8X,MDDD
2390      FOR I=1 TO Nu
2400        PRINT USING 2380;Fd(I);Bmax(Z,I);Xmaxd(Z,I);Bmin(Z,I);Xmind(Z,I)
2410      NEXT I
2420      IMAGE 10X,"UNIT FORCE ACTING AT",MDDD,"(DEGREES) CAUSES MAXIMUM BENDING
MOMENT=",M.DDD
2430      IMAGE 10X,"AND OCCURS AT",MDDD,"(DEGREES)"
2440      PRINT LIN(2)
2450      IF ABS(Mini1(Z))>Maxi1(Z) THEN GOTO Negative1
2460      PRINT USING 2420;Fd(C_max(Z));Maxi1(Z)
2470      PRINT USING 2430;Xmaxd(Z,C_max(Z))
2480      GOTO Shear
2490  Negative1:    !
2500      PRINT USING 2420;Fd(C_min(Z));Mini1(Z)
2510      PRINT USING 2430;Xmind(Z,C_min(Z))
```

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: "NOZ-5 : F8" PROGRAM LISTING FIGURE No. A12

```
2520 !  PRINT BENDING MOMENTS,SHEAR FORCES AND TANGENTIAL FORCES ALONG NOZZLE
2530 !  FOR UNIT RADIAL FORCE GIVING MAXIMUM BENDING MOMENTS
2540 Shear: !
2550     PRINT LIN(4);TAB(15);"BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG
NOZZLE"
2560     IF ABS(Mini1(Z))>Maxi1(Z) THEN GOTO Negative2
2570     PRINT TAB(15);"FOR UNIT RADIAL FORCE ACTING AT";Fd(C_max(Z));"(DEGREES)"
2580     GOTO Shear_table
2590 Negative2:  !
2600     PRINT TAB(15);"FOR UNIT RADIAL FORCE ACTING AT";Fd(C_min(Z));"(DEGREES)"
2610 Shear_table:!
2620     PRINT LIN(2);TAB(15);"X(DEGREES)";TAB(32);"Bm";TAB(47);"Sf";TAB(62);"Tf"
2630     IMAGE 15X,MDDD,10X,M.DDD,10X,M.DDD,10X,M.DDD
2640     C1=C_max(Z)
2650     IF ABS(Mini1(Z))>Maxi1(Z) THEN C1=C_min(Z)
2660     J=0
2670     FOR X=Te(Z) TO -Te(Z) STEP -15*PI/180
2680       Xd=X*180/PI
2690       J=J+1
2700       Phix(J)=X
2710       PRINT USING 2630;Xd;Mx(Z,C1,J);Sf(Z,C1,J);Tf(Z,C1,J)
2720     NEXT X
2730  NEXT Z
2740 ! PRINT EFFECT OF NOZZLE FOUNDATION ANGLES ON MAXIMUM BENDING MOMENTS
2750  IF Q$="N" THEN RETURN
2760  PRINT PAGE
2770  PRINT LIN(6);TAB(18);"EFFECT OF NOZZLE FOUNDATION ANGLE ON MAXIMUM BENDING
 MOMENT"
2780  PRINT LIN(1);TAB(26);"NOZZLE FOUNDATION HALF-ANGLES (DEGREES)"
2790  IMAGE 18X,DDD,11X,DDD,11X,DDD,11X,DDD,11X,DDD
2800  PRINT USING 2790;Ted(1);Ted(2);Ted(3);Ted(4);Ted(5)
2810  PRINT TAB(8);"Fd(I)";SPA(3);"Bm";SPA(5);"X";SPA(6);"Bm";SPA(5);"X";SPA(6);
"Bm";SPA(5);"X";SPA(6);"Bm";SPA(5);"X";SPA(6);"Bm";SPA(5);"X"
2820  FOR I=1 TO Nu
2830     IMAGE   6X,MDDD,3X,M.DDD,2X,MDDD,3X,M.DDD,2X,MDDD,3X,M.DDD,2X,MDDD,3X,M.
DDD,2X,MDDD,3X,M.DDD,2X,MDDD
2840     PRINT USING 2830;Fd(I);B1(1,I);X1(1,I);B1(2,I);X1(2,I);B1(3,I);X1(3,I);B
1(4,I);X1(4,I);B1(5,I);X1(5,I)
2850  NEXT I
2860  RETURN
```

CANADIAN
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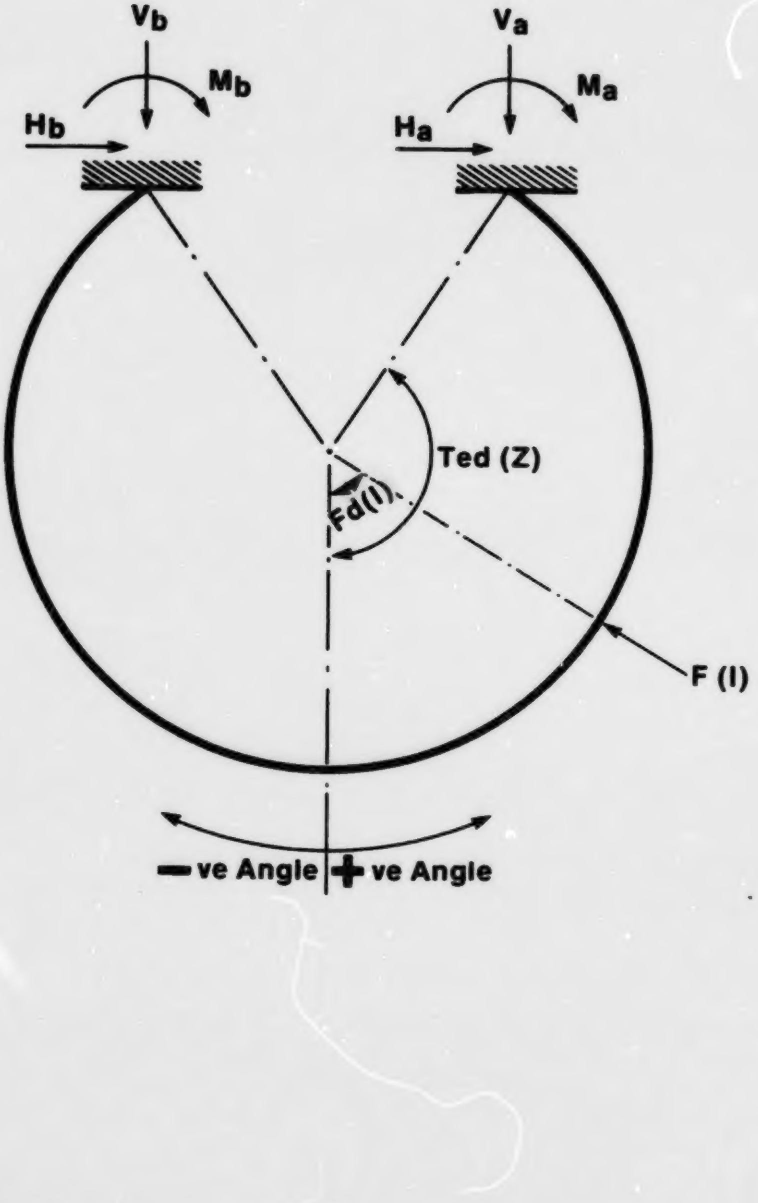
MEASUREMENT OF ICE PROPELLER
INTERACTION PARAMETERS

TITLE:

"NOZ-5 : F8"
PROGRAM LISTING

FIGURE No. A13

4. PROGRAM NOZ-5:F8 SAMPLE OUTPUTS


Vb
Mb
Hb
Va
Ma
Ha
Ted (Z)
Fd(I)
F (I)
— ve Angle
+ ve Angle

CANADIAN
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Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE:
STRENGTH OF NOZZLE PROGRAM
DOCUMENTATION "NOZ-5:F8"

APPENDIX A

```
                  ************************************
                  *  CALCULATION OF NOZZLE STRENGTH  *
                  ************************************

             NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 90


             REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

     Fd(I)      Ha        Va        Ma        Hb        Vb        Mb
       0      -.459      .500      .111      .459      .500     -.111
      45       .335      .530     -.200      .372      .177     -.153
      90      1.000      .000      .000      .000     -.000     -.000
     125      0.000      .000      .000      .000      .000      .000
     150      0.000      .000      .000      .000      .000      .000


             EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

             Fd(I)        Bmax        Xmax        Bmin        Xmin
               0          .151           0        -.068         47
              45          .192          45        -.200         90
              90          .000          90        -.000         90
             125          .000          90         .000         90
             150          .000          90         .000         90


  UNIT FORCE ACTING AT  45(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.200
  AND OCCURS AT  90(DEGREES)

       BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
       FOR UNIT RADIAL FORCE ACTING AT 45 (DEGREES)

       X(DEGREES)        Bm          Sf          Tf
          90           -.200       -.335       -.530
          75           -.096       -.461       -.425
          60            .030       -.556       -.292
          45            .192       -.612       -.130
          30            .096        .339       -.233
          15            .017        .267       -.313
           0           -.042        .177       -.372
         -15           -.075        .075       -.405
         -30           -.080       -.033       -.410
         -45           -.050       -.130       -.380
         -60           -.009       -.233       -.339
         -75            .063       -.313       -.267
         -90            .153       -.372       -.177
```

```
                 *************************************
                 *  CALCULATION OF NOZZLE STRENGTH   *
                 *************************************

                  UNIT CONCENTRATED RADIAL LOADS CASE

             NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 105


             REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

Fd(I)       Ha         Va         Ma         Hb         Vb         Mb
  0       -.349      .500       .135       .349       .500      -.135
 15       -.180      .540       .029       .438       .426      -.205
 30        .055      .534      -.093       .445       .332      -.231
 45        .325      .476      -.206       .382       .232      -.213
 60        .595      .362      -.281       .271       .138      -.159
 75        .821      .195      -.288       .145       .064      -.089
 90        .958     -.016      -.201       .042       .016      -.027


             EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

         Fd(I)      Bm(max)     X(max)      Bm(min)      X(min)
           0         .178          0         -.082         55
          15         .205       -105         -.108        -44
          30         .231       -105         -.119        -37
          45         .231         45         -.206        105
          60         .207         60         -.281        105
          75         .137         75         -.288        105
          90         .048         90         -.201        105


UNIT FORCE ACTING AT  75(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.288
AND OCCURS AT 105(DEGREES)


    BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
    FOR UNIT RADIAL FORCE ACTING AT 75 (DEGREES)

    X(DEGREES)       Bm            Sf            Tf
      105          -.288         -.742         -.401
       90          -.082         -.821         -.195
       75           .137         -.843          .024
       60           .096          .158         -.018
       45           .055          .148         -.058
       30           .019          .128         -.094
       15          -.011          .099         -.124
        0          -.032          .064         -.145
      -15          -.044          .024         -.157
      -30          -.045         -.018         -.158
      -45          -.035         -.058         -.148
      -60          -.015         -.094         -.128
      -75           .014         -.124         -.099
      -90           .050         -.145         -.064
     -105           .009         -.157         -.024
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TITLE:
"NOZ-5:F8"
Sample Outputs

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                  *************************************
                  *  CALCULATION OF NOZZLE STRENGTH   *
                  *************************************

                   UNIT CONCENTRATED RADIAL LOADS CASE


              NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 120



              REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

Fd(I)        Ha         Va         Ma         Hb         Vb         Mb
  0        -.259       .500       .162       .259       .500      -.162
 15        -.100       .520       .049       .359       .446      -.243
 30         .105       .498      -.002       .395       .368      -.281
 45         .336       .428      -.208       .371       .279      -.275
 60         .564       .311      -.307       .302       .189      -.231
 75         .760       .149      -.354       .206       .110      -.162
 90         .893      -.049      -.328       .107       .049      -.086



              EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

          Fd(I)        Bm(max)      X(max)        Bm(min)      X(min)
            0           .206          0           -.098          63
           15           .243        -120          -.123         -51
           30           .201        -120          -.138         -43
           45           .275        -120          -.208         120
           60           .257          60          -.307         120
           75           .208          75          -.354         120
           90           .125          90          -.328         120


    UNIT FORCE ACTING AT  75(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.354
    AND OCCURS AT 120(DEGREES)



        BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
        FOR UNIT RADIAL FORCE ACTING AT 75 (DEGREES)

        X(DEGREES)         Bm             Sf             Tf
           120            -.354          -.584          -.509
           105            -.186          -.696          -.340
            90             .006          -.760          -.149
            75             .208          -.773           .053
            60             .140           .233          -.007
            45             .087           .223          -.067
            30             .032           .190          -.123
            15            -.015           .160          -.170
             0            -.051           .110          -.206
           -15            -.072           .053          -.227
           -30            -.079          -.007          -.233
           -45            -.068          -.067          -.223
           -60            -.043          -.123          -.198
           -75            -.005          -.170          -.160
           -90             .045          -.206          -.110
          -105             .102          -.227          -.053
          -120             .162          -.233           .007
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                 ************************************
                 *  CALCULATION OF NOZZLE STRENGTH  *
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            NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 120


            REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

  Fd(I)       Ha         Va         Ma         Hb         Vb         Mb
    0       -.259      .500       .162       .259       .500      -.162
   45        .336      .428      -.208       .371       .279      -.275
   90        .893     -.049      -.328       .107       .049      -.086
  125       0.000      .000       .000       .000       .000       .000
  150       0.000      .000       .000       .000       .000       .000


           EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

        Fd(I)        Bmax        Xmax        Bmin        Xmin
          0          .206           0       -.098          63
         45          .275        -120       -.208         120
         90          .125          90       -.328         120
        125          .000         120        .000         120
        150          .000         120        .000         120


  UNIT FORCE ACTING AT  90(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.328
  AND OCCURS AT 120(DEGREES)

     BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
     FOR UNIT RADIAL FORCE ACTING AT 90 (DEGREES)


     X(DEGREES)      Bm          Sf          Tf
        120        -.328       -.798       -.404
        105        -.107       -.876       -.103
         90         .125       -.893        .049
         75         .096        .116        .020
         60         .066        .117       -.010
         45         .036        .110       -.040
         30         .009        .096       -.068
         15        -.014        .075       -.090
          0        -.030        .049       -.107
        -15        -.040        .020       -.116
        -30        -.041       -.010       -.117
        -45        -.034       -.040       -.110
        -60        -.020       -.068       -.096
        -75         .001       -.090       -.075
        -90         .027       -.107       -.049
       -105         .056       -.116       -.020
       -120         .086       -.117        .010
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************************************
*  CALCULATION OF NOZZLE STRENGTH  *
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  UNIT CONCENTRATED RADIAL LOADS CASE


NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 135



REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

Fd(I)        Ha        Va        Ma        Hb        Vb        Mb
    0     -.183      .500      .193      .183      .500     -.193
   15     -.031      .505      .070      .290      .461     -.284
   30      .155      .469     -.070      .345      .397     -.334
   45      .357      .389     -.210      .351      .318     -.340
   60      .553      .266     -.328      .313      .234     -.307
   75      .722      .104     -.405      .244      .155     -.243
   90      .839     -.008     -.421      .161      .008     -.162


EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

      Fd(I)      Bm(max)     X(max)      Bm(min)      X(min)
          0        .234          0        -.115         -70
         15        .284       -135        -.140         -58
         30        .334       -135        -.156         -49
         45        .340       -135        -.210         133
         60        .307       -135        -.320         135
         75        .266         75        -.405         135
         90        .198         90        -.421         135


UNIT FORCE ACTING AT  90(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.421
AND OCCURS AT 135(DEGREES)



    BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
    FOR UNIT RADIAL FORCE ACTING AT 90 (DEGREES)


    X(DEGREES)         Bm             Sf             Tf
       135           -.421          -.655          -.531
       120           -.233          -.770          -.344
       105           -.022          -.833          -.133
        90            .198          -.839           .000
        75            .153           .170           .043
        60            .106           .183          -.005
        45            .058           .176          -.052
        30            .015           .156          -.096
        15           -.022           .126          -.133
         0           -.051           .088          -.161
       -15           -.068           .043          -.170
       -30           -.073          -.005          -.183
        -45           -.065          -.052          -.176
        -60           -.046          -.096          -.156
        -75           -.016          -.133          -.126
        -90            .023          -.161          -.088
      -105             .068          -.170          -.043
      -120             .115          -.183           .005
      -135             .162          -.176           .052
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                 *  CALCULATION OF NOZZLE STRENGTH  *
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          NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 135


            REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS
 Fd(I)         Ha          Va          Ma          Hb          Vb          Mb
   0         -.183        .500        .193        .183        .500       -.193
  45          .357        .389       -.210        .351        .318       -.340
  90          .839       -.088       -.421        .161        .088       -.162
 125          .809       -.578       -.157        .010        .004       -.011
 150         0.000        .000        .000        .000        .000        .000


          EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS
      Fd(I)          Bmax          Xmax          Bmin          Xmin
        0            .234            0          -.115           -70
       45            .340         -135          -.210           133
       90            .198           90          -.421           135
      125            .015          125          -.157           135
      150            .000          135           .000           135


 UNIT FORCE ACTING AT  90(DEGREES).CAUSES MAXIMUM BENDING MOMENT=-.421
 AND OCCURS AT 135(DEGREES)


    BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
    FOR UNIT RADIAL FORCE ACTING AT 90 (DEGREES)


    X(DEGREES)         Bm             Sf            Tf
      135            -.421          -.655         -.531
      120            -.233          -.770         -.344
      105            -.022          -.833         -.133
       90             .198          -.839          .000
       75             .153           .178          .043
       60             .106           .183         -.005
       45             .058           .176         -.052
       30             .015           .156         -.096
       15            -.022           .126         -.133
        0            -.051           .088         -.161
      -15            -.068           .043         -.178
      -30            -.073          -.005         -.183
      -45            -.065          -.052         -.176
      -60            -.046          -.096         -.156
      -75            -.016          -.133         -.126
      -90             .023          -.161         -.088
     -105             .068          -.178         -.043
     -120             .115          -.183          .005
     -135             .162          -.176          .052
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                  *  CALCULATION OF NOZZLE STRENGTH  *
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              NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 150


              REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

Fd(I)          Ha          Va          Ma          Hb          Vb          Mb
  0          -.116        .500        .229        .116        .500       -.229
 45           .383        .358       -.208        .324        .349       -.409
 90           .798       -.123       -.496        .202        .123       -.247
125           .774       -.593       -.347        .046        .019       -.057
150           .500       -.866        .000        .000       -.000       -.000


              EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

        Fd(I)          Bmax          Xmax          Bmin          Xmin
          0            .263             0          -.135           -77
         45            .409          -150          -.221           137
         90            .257            90          -.496           150
        125            .068           125          -.347           150
        150            .000           150          -.000           150


UNIT FORCE ACTING AT  90(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.496
AND OCCURS AT 150(DEGREES)

    BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
    FOR UNIT RADIAL FORCE ACTING AT 90 (DEGREES)

    X(DEGREES)       Bm          Sf          Tf
      150          -.496       -.505       -.630
      135          -.343       -.651       -.477
      120          -.159       -.753       -.293
      105           .046       -.803       -.088
       90           .257       -.790        .123
       75           .201        .227        .066
       60           .140        .236        .005
       45           .078        .230       -.056
       30           .021        .207       -.113
       15          -.029        .171       -.163
        0          -.068        .123       -.202
      -15          -.093        .066       -.227
      -30          -.102        .005       -.236
      -45          -.096       -.056       -.230
      -60          -.073       -.113       -.207
      -75          -.037       -.163       -.171
      -90           .011       -.202       -.123
     -105           .060       -.227       -.066
     -120           .129       -.236       -.005
     -135           .190       -.230        .056
     -150           .247       -.207        .113
```

CANADIAN MARINE DRILLING LIMITED	**MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS**	**TITLE:** **"NOZ-5:F8" Sample Outputs**

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*************************************
*  CALCULATION OF NOZZLE STRENGTH   *
*************************************

    UNIT CONCENTRATED RADIAL LOADS CASE


NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 150



         REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

Fd(I)      Ha        Va        Ma        Hb        Vb        Mb
  0      -.116      .500      .229      .116      .500     -.229
 15       .031      .493      .096      .228      .473     -.330
 30       .202      .446     -.055      .298      .420     -.391
 45       .303      .358     -.208      .324      .349     -.409
 60       .555      .229     -.344      .312      .271     -.385
 75       .699      .066     -.446      .267      .193     -.327
 90       .798     -.123     -.496      .202      .123     -.247


         EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

      Fd(I)      Bm(max)      X(max)      Bm(min)      X(min)
        0         .263           0         -.135         -77
       15         .330        -150         -.156         -64
       30         .391        -150         -.172         -55
       45         .409        -150         -.221         137
       60         .385        -150         -.344         150
       75         .327        -150         -.446         150
       90         .257          90         -.496         150


UNIT FORCE ACTING AT  90(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.496
AND OCCURS AT 150(DEGREES)


   BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
   FOR UNIT RADIAL FORCE ACTING AT 90 (DEGREES)

   X(DEGREES)        Bm           Sf          Tf
     150           -.496        -.505       -.630
     135           -.343        -.651       -.477
     120           -.159        -.753       -.293
     105            .046        -.803       -.088
      90            .257        -.798        .123
      75            .201         .227        .066
      60            .140         .236        .005
      45            .078         .230       -.056
      30            .021         .207       -.113
      15           -.029         .171       -.163
       0           -.068         .123       -.202
     -15           -.093         ,066       -.227
     -30           -.102         .005       -.236
     -45           -.096        -.056       -.230
     -60           -.073        -.113       -.207
     -75           -.037        -.163       -.171
     -90            .011        -.202       -.123
    -105            .068        -.227       -.066
    -120            .129        -.236       -.005
    -135            .190        -.230        .056
    -150            .247        -.207        .113
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CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: "NOZ-5:F8" Sample Outputs

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*************************************
*  CALCULATION OF NOZZLE STRENGTH   *
*************************************

UNIT CONCENTRATED RADIAL LOADS CASE

NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 165


REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

Fd(I)      Ha        Va        Ma        Hb        Vb        Mb
  0      -.055      .500      .270      .055      .500     -.270
 15       .008      .485      .129      .171      .481     -.380
 30       .240      .431     -.032      .252      .435     -.450
 45       .412      .337     -.198      .295      .370     -.477
 60       .563      .205     -.351      .303      .295     -.462
 75       .608      .040     -.476      .278      .219     -.411
 90       .769     -.149     -.555      .231      .149     -.334


EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

Fd(I)      Bm(max)      X(max)      Bm(min)      X(min)
  0         .291          0         -.157          84
 15         .380       -165         -.171         -70
 30         .450       -165         -.184         -60
 45         .477       -165         -.245         141
 60         .462       -165         -.354         160
 75         .411       -165         -.476         165
 90         .334       -165         -.555         165

UNIT FORCE ACTING AT  90(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.555
AND OCCURS AT 165(DEGREES)


BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
FOR UNIT RADIAL FORCE ACTING AT 90 (DEGREES)

X(DEGREES)       Bm            Sf            Tf
  165          -.555         -.343         -.704
  150          -.442         -.514         -.592
  135          -.289         -.649         -.439
  120          -.106         -.741         -.256
  105           .094         -.782         -.055
   90           .298         -.769          .149
   75           .234          .261          .084
   60           .163          .274          .014
   45           .092          .269         -.058
   30           .024          .244         -.125
   15          -.035          .204         -.184
    0          -.081          .149         -.231
  -15          -.112          .084         -.261
  -30          -.125          .014         -.274
  -45          -.119         -.058         -.269
  -60          -.095         -.125         -.244
  -75          -.054         -.184         -.204
  -90           .000         -.231         -.149
 -105           .065         -.261         -.084
 -120           .136         -.274         -.014
 -135           .207         -.269          .058
 -150           .275         -.244          .125
 -165           .334         -.204          .184
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CANADIAN MARINE DRILLING LIMITED

MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS

TITLE: **"NOZ-5:F8" Sample Outputs**

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                    *************************************
                    *  CALCULATION OF NOZZLE STRENGTH  *
                    *************************************

                NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 165


                REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

    Fd(I)         Ha          Va          Ma          Hb          Vb          Mb
       0        -.055        .500        .270        .055        .500       -.270
      45         .412        .337       -.198        .295        .370       -.477
      90         .769       -.149       -.555        .231        .149       -.334
     125         .733       -.609       -.502        .087        .035       -.123
     150         .486       -.870       -.238        .014        .004       -.019


                EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

            Fd(I)          Bmax            Xmax            Bmin             Xmin
               0           .291               0           -.157               84
              45           .477            -165           -.245              141
              90           .334            -165           -.555              165
             125           .127             125           -.502              165
             150           .021             150           -.238              165


    UNIT FORCE ACTING AT  90(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.555
    AND OCCURS AT 165(DEGREES)

        BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
        FOR UNIT RADIAL FORCE ACTING AT 90 (DEGREES)

        X(DEGREES)        Bm              Sf              Tf
           165          -.555           -.343           -.704
           150          -.442           -.514           -.592
           135          -.289           -.649           -.439
           120          -.106           -.741           -.256
           105           .094           -.782           -.055
            90           .298           -.769            .149
            75           .234            .261            .004
            60           .163            .274            .014
            45           .092            .269           -.058
            30           .024            .244           -.125
            15          -.035            .204           -.184
             0          -.081            .149           -.231
           -15          -.112            .084           -.261
           -30          -.125            .014           -.274
           -45          -.119           -.058           -.269
           -60          -.095           -.125           -.244
           -75          -.054           -.184           -.204
           -90           .000           -.231           -.149
          -105           .065           -.261           -.084
          -120           .136           -.274           -.014
          -135           .207           -.269            .058
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                  ************************************
                  *  CALCULATION OF NOZZLE STRENGTH  *
                  ************************************

                   UNIT CONCENTRATED RADIAL LOADS CASE


               NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 165



               REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

 Fd(I)         Ha        Va        Ma        Hb        Vb        Mb
  90          .769     -.149     -.555      .231      .149     -.334
  95          .785     -.215     -.569      .211      .120     -.304
 100          .794     -.282     -.576      .191      .100     -.274
 105          .796     -.349     -.577      .170      .090     -.243
 110          .791     -.416     -.569      .148      .074     -.212
 115          .779     -.482     -.554      .127      .059     -.181
 120          .760     -.546     -.532      .106      .046     -.151



               EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

         Fd(I)       Bm(max)     X(max)      Bm(min)      X(min)
          90          .334        -165        -.555        165
          95          .304        -165        -.569        165
         100          .274        -165        -.576        165
         105          .243        -165        -.577        165
         110          .212        -165        -.569        165
         115          .181         115        -.554        165
         120          .154         120        -.532        165


UNIT FORCE ACTING AT 105(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.577
AND OCCURS AT 165(DEGREES)



     BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
     FOR UNIT RADIAL FORCE ACTING AT 105 (DEGREES)


     X(DEGREES)        Bm            Sf            Tf
       165           -.577         -.543         -.679
       150           -.413         -.700         -.515
       135           -.214         -.810         -.316
       120            .006         -.864         -.096
       105            .233         -.059          .131
        90            .192          .170          .090
        75            .145          .187          .043
        60            .095          .192         -.007
        45            .046          .184         -.056
        30            .000          .163         -.102
        15           -.039          .131         -.141
         0           -.068          .090         -.170
       -15           -.085          .043         -.187
       -30           -.090         -.007         -.192
       -45           -.082         -.056         -.184
       -60           -.061         -.102         -.163
       -75           -.029         -.141         -.131
       -90            .012         -.170         -.090
      -105            .059         -.187         -.043
      -120            .109         -.192          .007
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                    ************************************
                    *  CALCULATION OF NOZZLE STRENGTH  *
                    ************************************

                     UNIT CONCENTRATED RADIAL LOADS CASE


                NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 165



                REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

Fd(I)        Ha        Va        Ma        Hb        Vb        Mb
 103        .796     -.322     -.577      .170      .097     -.255
 104        .796     -.336     -.577      .174      .094     -.249
 105        .796     -.349     -.577      .170      .090     -.243
 106        .796     -.363     -.576      .166      .087     -.236
 107        .795     -.376     -.575      .161      .084     -.230



                EFFECT OF RADIAL FORCE ANGLE ON BENDING MOMENTS

        Fd(I)       Bm(max)      X(max)      Bm(min)       X(min)
         103         .255         -165        -.577         165
         104         .249         -165        -.577         165
         105         .243         -165        -.577         165
         106         .236         -165        -.576         165
         107         .230         -165        -.575         165


UNIT FORCE ACTING AT 103(DEGREES) CAUSES MAXIMUM BENDING MOMENT=-.577
AND OCCURS AT 165(DEGREES)



    BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE
    FOR UNIT RADIAL FORCE ACTING AT 103 (DEGREES)


    X(DEGREES)         Bm              Sf              Tf
      165            -.577           -.517           -.606
      150            -.420           -.677           -.520
      135            -.227           -.791           -.335
      120            -.011           -.851           -.119
      105             .213           -.852            .105
       90             .205            .178            .097
       75             .156            .197            .040
       60             .103            .203           -.005
       45             .051            .195           -.057
       30             .002            .173           -.106
       15            -.039            .140           -.147
        0            -.070            .097           -.178
      -15            -.089            .040           -.197
      -30            -.095           -.005           -.203
      -45            -.087           -.057           -.195
      -60            -.065           -.106           -.173
      -75            -.032           -.147           -.140
      -90             .011           -.178           -.097
     -105             .060           -.197           -.040
     -120             .113           -.203            .005
     -135             .165           -.195            .057
     -150             .214           -.173            .106
     -165             .255           -.140            .147
```

CANADIAN MARINE DRILLING LIMITED	MEASUREMENT OF ICE PROPELLER INTERACTION PARAMETERS	TITLE: "NOZ-5:F8" Sample Outputs

5. PROGRAM NOZ-5A:F8 LISTING

```
10  ! CALCULATION OF NOZZLE STRENGTH FOR  DISTRIBUTED RADIAL LOADS
20  ! PROGRAM SAVED AS A DATA FILE AND IS TO BE RUN ON HP9845B OR HP9845C
30  ! PROGRAM UPDATED 06/09/84 "NOZ-5A:F8"
40  ! REFER TO PROGRAM DOCUMENTATION FOR DEFINITIONS AND EQUATIONS
50  !
60  ! DECLARE VARIABLES
70  !
80   OPTION BASE 1
90  !
100   INTEGER J,I,K
110   REAL M(1:12,1:5),Sums1(5)
120   REAL Mx(1:12,1:361),Sums2(361)
130   REAL Phi(1:5),Phix(1:361)
140   REAL X,Xd
150   REAL Fd(12),F1(12),F(12),N(12),E(12)
160   REAL Lfh(12),Lfv(12),Lfm(12)
170   REAL Ha(12),Va(12),Ma(12),Hb(12),Vb(12),Mb(12)
180   REAL Mf(12,25),Sf(12,25),Tf(12,25),Sums3(25),Sums4(25),Sums5(25)
190   DIM A(3,3),B(3,3),L(3),G(3),Bmax(12),Bmin(12)
200   DIM Xmax(12),Xmin(12),Xmaxd(12),Xmind(12)
210  !
220 Main: !
230   GOSUB Input_data
240   GOSUB Angles
250   GOSUB Load_terms
260   GOSUB Multipliers
270   GOSUB Fixed_reactions
280   GOSUB Bending_moments
290   GOSUB Moments_forces
300   GOSUB Print_table1
310   STOP
320   END
330  !
340 Input_data: !
350   INPUT "ENTER: NOZZLE RADIUS (METRES)",R
360   INPUT "ENTER: NOZZLE FOUNDATION HALF-ANGLE (DEGREES)",Ted
370   INPUT "ENTER: NUMBER OF DISTRIBUTED RADIAL FORCES (MAX.12) ",Nu
380   FOR I=1 TO Nu
390     DISP "FORCE NO.";I;
400     INPUT "    ENTER: DISTRIBUTED RADIAL FORCE (UNIT FORCE)",F(I)
410     DISP "FORCE NO.";I;
420     INPUT "    ENTER: ANGLE OF RADIAL FORCE (DEGREES)",Fd(I)
430   NEXT I
440   INPUT " ENTER: THE AXIAL STRESS DEFORMATION FACTOR",A1
450   INPUT " ENTER: THE TRANSVERSE SHEAR DEFORMATION FACTOR",Be
460   RETURN
470  !
480 Angles: !
490  ! CALCULATE THE SINES AND COSINES OF THE NOZZLE FOUNDATION HALF-ANGLE
500  ! AND THE RADIAL FORCES ANGLES
510   Te=Ted*PI/180
520   S=SIN(Te)
530   C=COS(Te)
540   FOR I=1 TO Nu
550     F1(I)=Fd(I)*PI/180
560     N(I)=SIN(F1(I))
570     E(I)=COS(F1(I))
580   NEXT I
590   RETURN
600  !
610 Load_terms: !
620  ! CALCULATE THE LOADING TERMS:Lfh(I),Lfv(I),Lfm(I)
630   FOR I=1 TO Nu
640     Lfh(I)=F(I)*(E(I)/2*(1+C^2)-C-S*C*N(I)/2+N(I)/2*(Te+F1(I))+(A1+Be)*(N(I)
/2)*(Te+F1(I))+(A1-Be)*(S/2)*(S*E(I)+C*N(I)))
650     Lfv(I)=F(I)*(E(I)/2*(Te+F1(I))+S-1.5*C*(S*E(I)+C*N(I))+N(I)+(A1+Be)*(E(I
```

CANADIAN
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LIMITED

MEASUREMENT OF ICE PROPELLER
INTERACTION PARAMETERS

TITLE:

"NOZ-5A : F8"
PROGRAM LISTING

```
)/2)*(Te+F1(I))-(A1-Be)*(C/2)*(S*E(I)+C*H(I)))
660      Lfm(I)=F(I)*(1-C*E(I)+S*H(I))
670    NEXT I
680    RETURN
690   !
700 Multipliers: !
710   ! CALCULATE THE REACTION MULTIPLIERS:Bhh,BhV,Bvh,Bhm,Bmh,Bvv,Bvm,Bmv,Bmm
720    Bhh=Te+2*Te*C^2-3*S*C+A1*(Te+S*C)+Be*(Te-S*C)
730    Bhv=Bvh=2*S^2-2*Te*S*C
740    Bhm=Bmh=2*S-2*Te*C
750    Bvv=Te+2*Te*S^2-S*C+A1*(Te-S*C)+Be*(Te+S*C)
760    Bvm=Bmv=2*Te*S
770    Bmm=2*Te
780    RETURN
790   !
800 Fixed_reactions: !
810   ! CALCULATE THE REACTIONS AND BENDING MOMENT AT NOZZLE FOUNDATION "A"
820   ! BY SOVLING THE THREE DEFORMATION EQUATIONS SIMULTANEOUSLY
830    FOR I=1 TO Nu
840      A(1,1)=Bhh
850      A(1,2)=Bhv
860      A(1,3)=Bhm
870      A(2,1)=Bvh
880      A(2,2)=Bvv
890      A(2,3)=Bvm
900      A(3,1)=Bmh
910      A(3,2)=Bmv
920      A(3,3)=Bmm
930      L(1)=Lfh(I)
940      L(2)=Lfv(I)
950      L(3)=Lfm(I)
960      MAT B=INV(A)
970      MAT G=B*L
980      Ha(I)=G(1)
990      Va(I)=G(2)
1000     Ma(I)=G(3)*R
1010 ! CALCULATE THE REACTIONS AND BENDING MOMENT AT NOZZLE FOUNDATION "B"
1020     Hb(I)=F(I)*SIN(F1(I))-Ha(I)
1030     Vb(I)=F(I)*COS(F1(I))-Va(I)
1040     X=-Te
1050     Sx=SIN(F1(I)-X)
1060     IF F1(I)-X<=0 THEN Sx=0
1070     Mb(I)=-(Ma(I)+Ha(I)*R*(COS(X)-COS(Te))-Va(I)*R*(SIN(X)-SIN(Te))-F(I)*R*S
x)
1080 ! BENDING MOMENT AT NOZZLE FOUNDATION = -(BENDING MOMENT AT END OF NOZZLE)
1090  IF Fd(I)>Ted THEN Ha(I)=Va(I)=Ma(I)=Hb(I)=Vb(I)=Mb(I)=0
1100  NEXT I
1110  RETURN
1120 !
1130 Bending_moments:    !
1140  ! CALCULATE THE BENDING MOMENTS ALONG THE NOZZLE
1150  FOR I=1 TO Nu
1160    J=0
1170    FOR X=Te TO -Te STEP -PI/180
1180      J=J+1
1190      Phix(J)=X
1200      Sx=SIN(F1(I)-X)
1210      IF F1(I)-X<=0 THEN Sx=0
1220      Mx(I,J)=Ma(I)+Ha(I)*R*(COS(X)-COS(Te))-Va(I)*R*(SIN(X)-SIN(Te))-F(I)*R
*Sx
1230      IF Fd(I)>Ted THEN Mx(I,J)=0
1240    NEXT X
1250  NEXT I
1260 ! CALCULATE THE MAXIMUM POSITIVE AND NEGATIVE BENDING MOMENTS
1270  FOR I=1 TO Nu
1280    Xmax=Te
```

```
1290     Xmin=Te
1300     Bmax(I)=Mx(I,1)
1310     Bmin(I)=Mx(I,1)
1320     K=Ted*2+1
1330     FOR J=1 TO K
1340       Bmax(I)=MAX(Mx(I,J),Bmax(I))
1350       Bmin(I)=MIN(Mx(I,J),Bmin(I))
1360       IF Mx(I,J)=Bmax(I) THEN Xmax(I)=Te+(J-1)*-PI/180
1370       IF Mx(I,J)=Bmin(I) THEN Xmin(I)=Te+(J-1)*-PI/180
1380       IF (Bmax(I)<.00010) AND (Bmin(I)>-.00010) THEN Xmax(I)=Te
1390       IF (Bmax(I)<.00010) AND (Bmin(I)>-.00010) THEN Xmin(I)=Te
1400      Xmaxd(I)=Xmax(I)*180/PI
1410      Xmind(I)=Xmin(I)*180/PI
1420    NEXT J
1430  NEXT I
1440 !
1450 ! CALCULATE MAXIMUM BENDING MOMENTS FOR THE SUMMATION OF DISTRIBUTED LOADS
1460  MAT Sums2=CSUM(Mx)
1470  Sbmax=Sums2(1)
1480  Sbmax1=Sums2(1)
1490  Sbmin=Sums2(1)
1500  Sbmin1=Sums2(1)
1510  Sxmax=Te
1520  Sxmin=Te
1530  K=Ted*2+1
1540  FOR J=2 TO K
1550    IF Sums2(J)>Sbmax THEN Sbmax1=Sums2(J)
1560    IF Sums2(J)>Sbmax THEN Sxmax=Te+(J-1)*-.01745329252
1570    Sbmax=Sbmax1
1580    IF Sums2(J)<Sbmin THEN Sbmin1=Sums2(J)
1590    IF Sums2(J)<Sbmin THEN Sxmin=Te+(J-1)*-.01745329252
1600    Sbmin=Sbmin1
1610    Sxmaxd=Sxmax/.01745329252
1620    Sxmind=Sxmin/.01745329252
1630  NEXT J
1640  RETURN
1650 !
1660 Moments_forces:!
1670  ! CALCULATE BENDING MOMENTS,SHEAR FORCES AND TANGENTIAL FORCES
1680  FOR I=1 TO Nu
1690    J=0
1700    FOR X=Te TO -Te STEP -15*PI/180
1710      Xd=X*180/PI
1720      J=J+1
1730      Phix(J)=X
1740      Sx=SIN(F1(I)-X)
1750      Cx=COS(F1(I)-X)
1760      IF F1(I)-X<=0 THEN Sx=0
1770      IF F1(I)-X<=0 THEN Cx=0
1780      Mf(I,J)=Ma(I)+Ha(I)*R*(COS(X)-COS(Te))-Va(I)*R*(SIN(X)-SIN(Te))-F(I)*R
*Sx
1790      Sf(I,J)=-Ha(I)*SIN(X)-Va(I)*COS(X)+F(I)*Cx
1800      Tf(I,J)=-(-Ha(I)*COS(X)+Va(I)*SIN(X)+F(I)*Sx)
1810    NEXT X
1820  NEXT I
1830  MAT Sums3=CSUM(Mf)
1840  MAT Sums4=CSUM(Sf)
1850  MAT Sums5=CSUM(Tf)
1860  RETURN
1870 !
1880 Print_table1:   !
1890  PRINT PAGE
1900  PRINT TAB(24);"************************************"
1910  PRINT TAB(24);"*";TAB(27);"CALCULATION OF NOZZLE STRENGTH";TAB(59);"*"
1920  PRINT TAB(24);"************************************"
1930  PRINT LIN(1);TAB(27);" DISTRIBUTED RADIAL LOADS CASE"
```

```
1940  PRINT LIN(2);TAB(20);"NOZZLE FOUNDATION HALF-ANGLE (DEGREES)=";Ted
1950  PRINT LIN(4);TAB(20);"REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS"
1960  PRINT LIN(1);TAB(10);"Fd(I)";TAB(22);"Ha";TAB(32);"Va";TAB(42);"Ma";TAB(52
);"Hb";TAB(62);"Vb";TAB(72);"Mb"
1970  IMAGE 10X,DDD,5X,MD.DDD,5X,M.DDD,5X,M.DDD,5X,M.DDD,5X,M.DDD,5X,M.DDD
1980  IMAGE 10X,"SUM",4X,MDD.DDD,3X,MDD.DDD,3X,MDD.DDD,3X,MDD.DDD,3X,MDD.DDD,3X,
MDD.DDD
1990  FOR I=1 TO Nu
2000    PRINT USING 1970;Fd(I);Ha(I);Va(I);Ma(I);Hb(I);Vb(I);Mb(I)
2010  NEXT I
2020  PRINT LIN(1)
2030  PRINT USING 1980;SUM(Ha);SUM(Va);SUM(Ma);SUM(Hb);SUM(Vb);SUM(Mb)
2040 !
2050  PRINT LIN(4);TAB(26);"MAXIMUM BENDING MOMENTS ALONG NOZZLE"
2060  PRINT LIN(1);TAB(18);"Fd(I)";TAB(29);"Bm(max)";TAB(41);"X(max)";TAB(53);"B
m(min)";TAB(66);"X(min)"
2070  IMAGE 18X,DDD,7X,M.DDD,8X,MDDD,8X,M.DDD,8X,MDDD
2080  IMAGE 18X,"SUM",5X,MDD.DDD,8X,MDDD,6X,MDD.DDD,8X,MDDD
2090  FOR I=1 TO Nu
2100    PRINT USING 2070;Fd(I);Bmax(I);Xmaxd(I);Bmin(I);Xmind(I)
2110  NEXT I
2120  PRINT LIN(1)
2130  PRINT USING 2080;Sbmax;Sxmaxd;Sbmin;Sxmind
2140 !
2150  PRINT LIN(4);TAB(18);"BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NO
ZZLE"
2160  PRINT LIN(2);TAB(20);"X";TAB(36);"Bm";TAB(53);"Sf";TAB(70);"Tf"
2170  IMAGE 17X,MDDD,10X,MDD.DDD,10X,MDD.DDD,10X,MDD.DDD
2180  J=0
2190  FOR X=Te TO -Te STEP -15*PI/180
2200    Xd=X*180/PI
2210    J=J+1
2220    Phix(J)=X
2230    PRINT USING 2170;Xd;Sums3(J);Sums4(J);Sums5(J)
2240  NEXT X
2250  RETURN
```

6. PROGRAM NOZ-5A:F8 SAMPLE OUTPUTS

```
                    *************************************
                    *  CALCULATION OF NOZZLE STRENGTH  *
                    *************************************

                         DISTRIBUTED RADIAL LOADS CASE

                  NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 165


                  REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

     Fd(I)       Ha        Va        Ma        Hb        Vb        Mb
      80        .144     -.004     -.102      .053      .039     -.077
      85        .150     -.017     -.107      .050      .034     -.072
      90        .154     -.030     -.111      .046      .030     -.067
      95        .157     -.043     -.114      .042      .026     -.061
     100        .159     -.056     -.115      .038      .022     -.055

     SUM        .763     -.150     -.549      .229      .150     -.332


                     MAXIMUM BENDING MOMENTS ALONG NOZZLE

          Fd(I)      Bm(max)     X(max)       Bm(min)       X(min)
           80         .077        -165         -.102          165
           85         .072        -165         -.107          165
           90         .067        -165         -.111          165
           95         .061        -165         -.114          165
          100         .055        -165         -.115          165

          SUM         .332        -165         -.549          165


          BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE

          X            Bm           Sf           Tf
         165         -.549        -.343        -.698
         150         -.436        -.512        -.586
         135         -.284        -.646        -.433
         120         -.102        -.736        -.251
         105          .097        -.776        -.052
          90          .248        -.367         .098
          75          .236         .260         .086
          60          .165         .274         .016
          45          .094         .268        -.056
          30          .026         .245        -.123
          15         -.033         .205        -.183
           0         -.080         .150        -.229
         -15         -.111         .086        -.260
         -30         -.124         .016        -.274
         -45         -.119        -.056        -.260
         -60         -.095        -.123        -.245
         -75         -.055        -.183        -.205
         -90         -.001        -.229        -.150
        -105          .064        -.260        -.086
        -120         -.059        -.293        -.404
        -135          .031        -.388        -.314
        -150          .142        -.456        -.203
        -165          .267        -.493        -.078
```

```
*************************************
*  CALCULATION OF NOZZLE STRENGTH  *
*************************************

     DISTRIBUTED RADIAL LOADS CASE


  NOZZLE FOUNDATION HALF-ANGLE (DEGREES)= 165



   REACTIONS AND BENDING MOMENTS AT NOZZLE FOUNDATIONS

 Fd(I)      Ha        Va        Ma        Hb        Vb        Mb
  -10     -.027      .098      .070     -.008      .099     -.036
   -5     -.019      .099      .062      .002      .100     -.045
    0     -.011      .100      .054      .011      .100     -.054
    5     -.002      .100      .045      .019      .099     -.062
   10      .008      .099      .036      .027      .098     -.070

  SUM     -.052      .496      .267      .052      .496     -.267


          MAXIMUM BENDING MOMENTS ALONG NOZZLE

      Fd(I)      Bm(max)     X(max)      Bm(min)      X(min)
       -10        .070        165        -.033         75
        -5        .062        165        -.032         79
         0        .058          0        -.031         84
         5        .062       -165        -.032        -79
        10        .070       -165        -.033        -75

       SUM        .267        165        -.154        -84


      BENDING MOMENTS,SHEAR AND TANGENTIAL FORCES ALONG NOZZLE

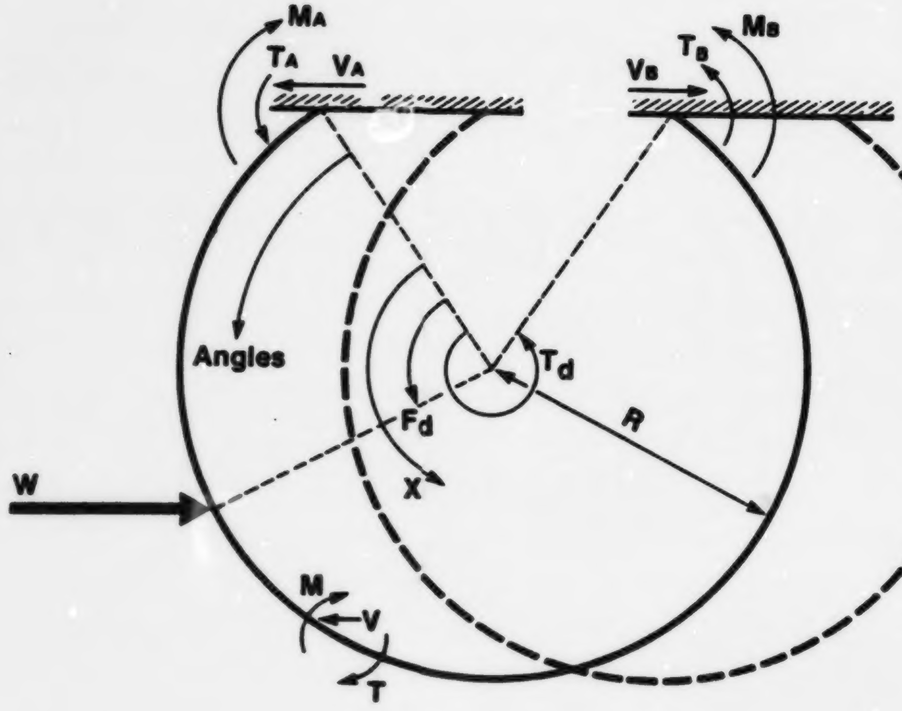
       X            Bm           Sf           Tf
      165          .267         .493        -.078
      150          .142         .456        -.203
      135          .031         .388        -.314
      120         -.059         .293        -.404
      105         -.121         .179        -.466
       90         -.151         .052        -.496
       75         -.140        -.078        -.493
       60         -.111        -.203        -.456
       45         -.043        -.314        -.388
       30          .051        -.404        -.293
       15          .166        -.466        -.179
        0          .240        -.100        -.104
      -15          .166         .466        -.179
      -30          .051         .404        -.293
      -45         -.043         .314        -.388
      -60         -.111         .203        -.456
      -75         -.140         .078        -.493
      -90         -.151        -.052        -.496
     -105         -.121        -.179        -.466
     -120          .134        -.274        -.016
     -135          .205        -.268         .056
     -150          .273        -.245         .123
     -165          .332        -.205         .183
```

7. PROGRAM DOCUMENTATION NOZ-5B:F8 LISTING

```
10  !  PROGRAM TO CALCULATE BENDING MOMENT,TWISTING MOMENT AND TRANSVERSE
20  !  SHEAR FOR CONCENTRATED LOAD ACTING NORMAL TO PLANE OF CURVATURE.
30  !  PROGRAM "NOZ-5B:F8" UPDATED 24/09/84
40  !  RUN ON HP9845A OR HP9845C
50  !  REFERENCE:"FORMULAS FOR STRESS AND STRAIN",TABLE 19,CASE 1e
60  !  DECLARE VARIABLES
70  !  OPTION BASE 1
80  !
90    INTEGER J
100   INTEGER Td,Fd,Xd(37)
110   REAL Tr,Fr,W
120   REAL Be,X(37),Phi(37)
130   REAL V(37),M(37),T(37)
140 !
150 Main:  !
160   GOSUB Input_data
170   GOSUB Angles
180   GOSUB Constants
190   GOSUB Reactions
200   GOSUB Moments
210   GOSUB Print_table
220   STOP
230   END
240   ! !
250 Input_data:  !
260   INPUT "ENTER: NOZZLE RADIUS (METRES)",R
270   INPUT "ENTER: NOZZLE FOUNDATION ANGLE (DEGREES)",Td
280   INPUT "ENTER: ANGLE FROM THE LEFT END TO POSITION OF LOADING(DEG)",Fd
290   INPUT "ENTER: VALUE OF Be (Be=EI/GK)",Be
300   INPUT "ENTER: APPLIED LOAD NORMAL TO PLANE OF CURVATURE",W
310   RETURN
320   !
330 Angles:  !
340   Tr=Td*PI/180
350   Fr=Fd*PI/180
360   St=SIN(Tr)
370   Sf=SIN(Fr)
380   Ct=COS(Tr)
390   Cf=COS(Fr)
400   S=SIN(Tr-Fr)
410   C=COS(Tr-Fr)
420   RETURN
430   !
440 Constants:  !
450   C1=(1+Be)/2*Tr*St-Be*(1-Ct)
460   C2=(1+Be)/2*(Tr*Ct-St)
470   C3=-Be*(Tr-St)-(1+Be)/2*(Tr*Ct-St)
480   C4=(1+Be)/2*Tr*Ct+(1-Be)/2*St
490   C5=-(1+Be)/2*Tr*St
500   C6=C1
510   C7=C5
520   C8=(1-Be)/2*St-(1+Be)/2*Tr*Ct
530   C9=C2
540   Ca1=(1+Be)/2*(Tr-Fr)*S-Be*(1-C)
550   Ca2=(1+Be)/2*((Tr-Fr)*C-S)
560   Ca3=-Be*(Tr-Fr-S)-Ca2
570   Ca4=(1+Be)/2*(Tr-Fr)*C+(1-Be)/2*S
580   Ca5=-(1+Be)/2*(Tr-Fr)*S
590   Ca6=Ca1
600   Ca7=Ca5
610   Ca8=(1-Be)/2*S-(1+Be)/2*(Tr-Fr)*C
620   Ca9=Ca2
630   Ca12=(1+Be)/2*((Tr-Fr)*S-2+2*C)
640   Ca13=Be*(1-C-(Tr-Fr)^2/2)-Ca12
650   Ca15=-(1+Be)/2*(S-(Tr-Fr)*C)
660   Ca16=-Be*(Tr-Fr-S)-Ca15
```

```
670   Ca18=1-C-(1+Be)/2*(Tr-Fr)*S
680   Ca19=Ca12
690   RETURN
700   !
710 Reactions:  !
720   Va=W*(Ca3*(C4*C8-C5*C7)+Ca6*(C2*C7-C1*C8)+Ca9*(C1*C5-C2*C4))/(C1*(C5*C9-C6
*C8)+C4*(C3*C8-C2*C9)+C7*(C2*C6-C3*C5))
730   Ma=W*R*(Ca3*(C5*C9-C6*C8)+Ca6*(C3*C8-C2*C9)+Ca9*(C2*C6-C3*C5))/(C1*(C5*C9-
C6*C8)+C4*(C3*C8-C2*C9)+C7*(C2*C6-C3*C5))
740   Ta=W*R*(Ca3*(C6*C7-C4*C9)+Ca6*(C1*C9-C3*C7)+Ca9*(C3*C4-C1*C6))/(C1*(C5*C9-
C6*C8)+C4*(C3*C8-C2*C9)+C7*(C2*C6-C3*C5))
750   Vb=Va-W
760   Mb=Va*R*St+Ma*Ct-Ta*St-W*R*S
770   Tb=Va*R*(1-Ct)+Ma*St+Ta*Ct-W*R*(1-C)
780   RETURN
790 Moments:  !
800 ! CALCULATE THE TRANSVERSE SHEAR,BENDING MOMENT AND TWISTING MOMENT
810 ! ALONG NOZZLE
820   J=0
830   FOR X=0 TO Tr STEP 10*PI/180
840     J=J+1
850     Phi(J)=X
860     IF X>Fr THEN Xf=1
870     IF X<Fr THEN Xf=0
880     V(J)=Va-W*Xf
890     M(J)=Va*R*SIN(X)+Ma*COS(X)-Ta*SIN(X)-W*R*SIN(X-Fr)*Xf
900     T(J)=Va*R*(1-COS(X))+Ma*SIN(X)+Ta*COS(X)-W*R*(1-COS(X-Fr))*Xf
910     IF Fr>Tr THEN V(J)=M(J)=T(J)=0
920   NEXT X
930   RETURN
940   !
950 Print_table:  !
960   PRINT PAGE
970   PRINT TAB(24);"************************************"
980   PRINT TAB(24);"*";TAB(27);"CALCULATION OF NOZZLE STRENGTH";TAB(59);"*"
990   PRINT TAB(24);"************************************"
1000  PRINT LIN(1);TAB(25);"UNIT CONCENTRATED AXIAL LOAD CASE "
1010  PRINT LIN(2);TAB(23);"NOZZLE FOUNDATION ANGLE (DEGREES)=";Td
1020 ! PRINT TABLE OF REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIO
NS
1030  PRINT LIN(4);TAB(13);"REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOU
NDATIONS"
1040  PRINT LIN(1);TAB(12);"Fd";TAB(22);"Va";TAB(32);"Ma";TAB(42);"Ta";TAB(52);"
Vb";TAB(62);"Mb";TAB(72);"Tb"
1050  IMAGE 10X,DDD,5X,MD.DDD,4X,MD.DDD,4X,MD.DDD,4X,MD.DDD,4X,MD.DDD,4X,MD.DDD
1060  PRINT USING 1050;Fd;Va;Ma;Ta;Vb;Mb;Tb
1070 ! PRINT TABLE OF REACTIONS,BENDING AND TWISTING MOMENTS ALONG NOZZLE
1080  PRINT LIN(4);TAB(15);"TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG N
OZZLE"
1090  PRINT LIN(2);TAB(18);"X";TAB(34);"V";TAB(51);"M";TAB(68);"T"
1100  IMAGE 15X,MDDD,11X,MD.DDD,11X,MD.DDD,11X,MD.DDD
1110  J=0
1120  FOR X=0 TO Tr STEP 10*PI/180
1130    Xd=X*180/PI
1140    J=J+1
1150    Phi(J)=X
1160    PRINT USING 1100;Xd;V(J);M(J);T(J)
1170  NEXT X
1180  RETURN
1190  PRINT LIN(4);"Tr=";Tr;"Fr=";Fr;"St=";St;"Sf=";Sf
1200  PRINT "Ct=";Ct;"Cf=";Cf;"S=";S;"C=";C
1210  PRINT "C1=";C1;"C2=";C2;"C3=";C3;"C4=";C4
1220  PRINT "C5=";C5;"C6=";C6;"C7=";C7;"C8=";C8;"C9=";C9
1230  PRINT "Ca1=";Ca1;"Ca2=";Ca2;"Ca3=";Ca3;"Ca4=";Ca4
1240  PRINT "Ca5=";Ca5;"Ca6=";Ca6;"Ca7=";Ca7;"Ca8=";Ca8
1250  PRINT "Ca9=";Ca9;"Ca10=";Ca10;"Ca12=";Ca12;"Ca13=";Ca13
1260  PRINT "Ca15=";Ca15;"Ca16=";Ca16;"Ca18=";Ca18;"Ca19=";Ca19
```

8. PROGRAM "NOZ-5B:F8" SAMPLE OUTPUTS


M_A
T_A
V_A
V_B
T_B
M_B
Angles
T_d
F_d
R
X
W
M
V
T

CANADIAN
MARINE
DRILLING
LIMITED

Strength Requirements
For Nozzles For Ice
Transitting Ships

TITLE: Axial Load Case Notations

FIGURE No. A-3

```
**************************************
*  CALCULATION OF NOZZLE STRENGTH  *
**************************************

UNIT CONCENTRATED AXIAL LOAD CASE

NOZZLE FOUNDATION ANGLE (DEGREES)= 180
```

LOAD AT THE FOUNDATION

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

 Fd        Va        Ma        Ta        Vb        Mb        Tb
180     0.000     0.000     0.000    -1.000     0.000     0.000


     TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

        X              V               M               T
        0          0.000           0.000           0.000
       15          0.000           0.000           0.000
       30          0.000           0.000           0.000
       45          0.000           0.000           0.000
       60          0.000           0.000           0.000
       75          0.000           0.000           0.000
       90          0.000           0.000           0.000
      105          0.000           0.000           0.000
      120          0.000           0.000           0.000
      135          0.000           0.000           0.000
      150          0.000           0.000           0.000
      165          0.000           0.000           0.000
      180          0.000           0.000           0.000
```

```
*************************************
*  CALCULATION OF NOZZLE STRENGTH  *
*************************************

UNIT CONCENTRATED AXIAL LOAD CASE

NOZZLE FOUNDATION ANGLE (DEGREES)= 180
```

β=20

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

Fd        Va        Ma        Ta        Vb        Mb        Tb
90       .500     -.500      .182     -.500     -.500     -.182


TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

  X                 V                  M                  T
   0              .500              -.500               .182
  15              .500              -.401               .063
  30              .500              -.274              -.026
  45              .500              -.128              -.079
  60              .500               .026              -.092
  75              .500               .178              -.065
  90              .500               .318              0.000
 105             -.500               .178               .065
 120             -.500               .026               .092
 135             -.500              -.128               .079
 150             -.500              -.274               .026
 165             -.500              -.401              -.063
 180             -.500              -.500              -.182


Tr= 3.1415926536 Fr= 1.5707963268 St= 0 Sf= 1
Ct=-1 Cf= 0 S= 1 C= 0
C1=-1.8 C2=-2.98451302092 C3= .15707963268 C4=-2.98451302092
C5= 0 C6=-1.8 C7= 0 C8= 2.98451302092 C9=-2.98451302092
Ca1= .59225651046 Ca2=-.95 Ca3= .43628330588 Ca4= .05
Ca5=-1.49225651046 Ca6= .59225651046 Ca7=-1.49225651046 Ca8= .05
Ca9=-.95 Ca10= 0 Ca12=-.40774348954 Ca13= .197412994405
Ca15=-.95 Ca16= .43628330588 Ca18=-.49225651046 Ca19=-.40774348954
```

```
*************************************
*  CALCULATION OF NOZZLE STRENGTH   *
*************************************

     UNIT CONCENTRATED AXIAL LOAD CASE

   NOZZLE FOUNDATION ANGLE (DEGREES)= 165
```

$\beta = 20$

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

Fd        Va        Ma        Ta        Vb        Mb        Tb
90       .417     -.399      .135     -.583     -.507     -.155


  TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

     X              V               M              T
     0            .417          -.399            .135
    10            .417          -.344            .070
    20            .417          -.278            .015
    30            .417          -.204           -.027
    40            .417          -.124           -.056
    50            .417          -.040           -.070
    60            .417           .045           -.070
    70            .417           .129           -.055
    80            .417           .209           -.025
    90            .417           .282            .018
   100           -.583           .174            .058
   110           -.583           .060            .078
   120           -.583          -.056            .078
   130           -.583          -.170            .059
   140           -.583          -.279            .019
   150           -.583          -.379           -.038
   160           -.583          -.468           -.112
```

CANADIAN MARINE DRILLING LIMITED	**STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS**	**TITLE:** **Program "NOZ-5B:F8" Listing**
		APPENDIX A

```
*************************************
*  CALCULATION OF NOZZLE STRENGTH  *
*************************************

UNIT CONCENTRATED AXIAL LOAD CASE


NOZZLE FOUNDATION ANGLE (DEGREES)= 165
```

$\beta = 10$

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS
Fd        Va        Ma        Ta        Vb        Mb        Tb
90       .419     -.402      .135     -.581     -.504     -.152


TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

    X            V            M            T
    0          .419        -.402         .135
   10          .419        -.346         .070
   20          .419        -.280         .015
   30          .419        -.206        -.028
   40          .419        -.125        -.057
   50          .419        -.041        -.071
   60          .419         .045        -.071
   70          .419         .129        -.056
   80          .419         .210        -.026
   90          .419         .284         .017
  100         -.581         .176         .057
  110         -.581         .062         .078
  120         -.581        -.053         .079
  130         -.581        -.167         .060
  140         -.581        -.276         .021
  150         -.581        -.376        -.036
  160         -.581        -.465        -.110
```

```
                   ************************************
                   *  CALCULATION OF NOZZLE STRENGTH  *
                   ************************************

                    UNIT CONC[illegible]

                  NOZZLE FOUNDATION ANGLE (DEGREES)= 330
```

$\beta = 0.9$

```
      REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

   Fd          Va        Ma         Ta         Vb         Mb         Tb
   165        .500     -.444       .899      -.500      -.444      -.899


          TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

            X               V                M                T
            0             .500            -.444             .899
           15             .500            -.532             .770
           30             .500            -.584             .623
           45             .500            -.596             .468
           60             .500            -.567             .315
           75             .500            -.500             .175
           90             .500            -.399             .056
          105             .500            -.270            -.032
          120             .500            -.123            -.084
          135             .500             .032            -.096
          150             .500             .185            -.067
          165             .500             .325             .000
          180            -.500             .185             .067
          195            -.500             .032             .096
          210            -.500            -.123             .084
          225            -.500            -.270             .032
          240            -.500            -.399            -.056
          255            -.500            -.500            -.175
          270            -.500            -.567            -.315
          285            -.500            -.596            -.468
          300            -.500            -.584            -.623
          315            -.500            -.532            -.770
          330            -.500            -.444            -.899


Tr= 5.75958653161 Fr= 2.8797932658 St=-.49999999998 Sf= .258819045096
Ct= .866025403769 Cf=-.965925826261 S= .258819045083 C=-.965925826261
C1=-2.85638073902 C2= 5.21355083898 C3=-10.8471787174 C4= 4.713550839
C5= 2.73580360241 C6=-2.85638073902 C7= 2.73580360241 C8=-4.763550939 C9=
 5.21355083898
Ca1=-1.06125516769 Ca2=-2.88846144808 Ca3= .52958464942 Ca4=-2.629642403
Ca5=-.708078075939 Ca6=-1.06125516769 Ca7=-.708078075939 Ca8= 2.6555243075
Ca9=-2.88846144808 Ca10= 0 Ca12=-3.02718099396 Ca13= 1.06457007338
Ca15=-2.88846144808 Ca16= .52958464942 Ca18= 1.25784775032 Ca19=-3.02718099396
```

```
*************************************
*  CALCULATION OF NOZZLE STRENGTH  *
*************************************

UNIT CONCENTRATED AXIAL LOAD CASE

NOZZLE FOUNDATION ANGLE (DEGREES)= 330
```

$\beta=10$

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

 Fd        Va        Ma        Ta        Vb        Mb        Tb
165       .500     -.681      .835     -.500     -.681     -.835


TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

   X            V            M            T
   0          .500        -.681         .835
  15          .500        -.744         .648
  30          .500        -.757         .450
  45          .500        -.718         .256
  60          .500        -.631         .078
  75          .500        -.500        -.071
  90          .500        -.335        -.181
 105          .500        -.148        -.244
 120          .500         .050        -.257
 135          .500         .244        -.218
 150          .500         .422        -.131
 165          .500         .571         .000
 180         -.500         .422         .131
 195         -.500         .244         .218
 210         -.500         .050         .257
 225         -.500        -.148         .244
 240         -.500        -.335         .181
 255         -.500        -.500         .071
 270         -.500        -.631        -.078
 285         -.500        -.718        -.256
 300         -.500        -.757        -.450
 315         -.500        -.744        -.648
 330         -.500        -.681        -.835
```

```
***********************************
*  CALCULATION OF NOZZLE STRENGTH  *
***********************************

UNIT CONCENTRATED AXIAL LOAD CASE

NOZZLE FOUNDATION ANGLE (DEGREES)= 330
```

$\beta\cdot 20$

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

Fd          Va        Ma         Ta         Vb         Mb         Tb
165        .500     -.702       .829      -.500      -.702      -.829


TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

        X              V              M              T
        0            .500          -.702           .829
       10            .500          -.749           .703
       20            .500          -.773           .569
       30            .500          -.773           .434
       40            .500          -.750           .301
       50            .500          -.704           .174
       60            .500          -.636           .057
       70            .500          -.550          -.047
       80            .500          -.446          -.134
       90            .500          -.329          -.202
      100            .500          -.203          -.249
      110            .500          -.069          -.273
      120            .500           .066          -.2[illegible]3
      130            .500           .199          -.250
      140            .500           .326          -.204
      150            .500           .443          -.136
      160            .500           .547          -.050
      170           -.500           .547           .050
      180           -.500           .443           .136
      190           -.500           .326           .204
      200           -.500           .199           .250
      210           -.500           .066           .273
      220           -.500          -.069           .273
      230           -.500          -.203           .249
      240           -.500          -.329           .202
      250           -.500          -.446           .134
      260           -.500          -.550           .047
      270           -.500          -.636          -.057
      280           -.500          -.704          -.174
      290           -.500          -.750          -.301
      300           -.500          -.773          -.434
      310           -.500          -.773          -.569
      320           -.500          -.749          -.703
      330           -.500          -.702          -.829
```

**CANADIAN
MARINE
DRILLING
LIMITED**

**STRENGTH REQUIREMENTS FOR
NOZZLES FOR ICE
TRANSITING SHIPS**

TITLE: **Program "NOZ-5B:F8" Listing**

APPENDIX A

```
            ************************************
            *  CALCULATION OF NOZZLE STRENGTH  *
            ************************************

             UNIT CONCENTRATED AXIAL LOAD CASE


           NOZZLE FOUNDATION ANGLE (DEGREES)= 330
```

β= 0°

```
    REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

 Fd         Va         Ma         Ta         Vb         Mb         Tb
255        .072       .029       .220      -.928      -.867      -.555



      TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

       X               V                M                 T
       0             .072             .029              .220
      15             .072            -.010              .223
      30             .072            -.049              .215
      45             .072            -.085              .197
      60             .072            -.114              .171
      75             .072            -.136              .130
      90             .072            -.140              .101
     105             .072            -.151              .061
     120             .072            -.143              .023
     135             .072            -.125             -.013
     150             .072            -.099             -.042
     165             .072            -.066             -.064
     180             .072            -.029             -.077
     195             .072             .010             -.079
     210             .072             .049             -.071
     225             .072             .085             -.054
     240             .072             .114             -.028
     255             .072             .136              .005
     270            -.920            -.110              .009
     285            -.928            -.349             -.052
     300            -.928            -.564             -.172
     315            -.920            -.741             -.344
     330            -.920            -.867             -.555
```

```
***********************************
*  CALCULATION OF NOZZLE STRENGTH  *
***********************************

UNIT CONCENTRATED AXIAL LOAD CASE

NOZZLE FOUNDATION ANGLE (DEGREES)= 330
```

$\beta=10$

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

  Fd         Va        Ma        Ta        Vb        Mb        Tb
 255       .070     -.069      .178     -.930     -.972     -.543


TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

   X              V              M              T
   0            .070          -.069           .178
  15            .070          -.095           .156
  30            .070          -.114           .129
  45            .070          -.125           .097
  60            .070          -.128           .064
  75            .070          -.122           .031
  90            .070          -.107           .001
 105            .070          -.086          -.024
 120            .070          -.058          -.043
 135            .070          -.027          -.054
 150            .070           .007          -.057
 165            .070           .039          -.051
 180            .070           .069          -.037
 195            .070           .095          -.015
 210            .070           .114           .012
 225            .070           .125           .044
 240            .070           .128           .077
 255            .070           .122           .110
 270           -.930          -.152           .106
 285           -.930          -.414           .031
 300           -.930          -.649          -.109
 315           -.930          -.839          -.305
 330           -.930          -.972          -.543
```

```
*************************************
*  CALCULATION OF NOZZLE STRENGTH  *
*************************************

     UNIT CONCENTRATED AXIAL LOAD CASE

   NOZZLE FOUNDATION ANGLE (DEGREES)= 330
```

β= 20

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

Fd          Va        Ma        Ta        Vb        Mb        Tb
255        .070     -.070      .174     -.930     -.982     -.542


   TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

       X              V               M               T
       0            .070           -.070            .174
      10            .070           -.095            .158
      20            .070           -.109            .141
      30            .070           -.120            .121
      40            .070           -.126            .099
      50            .070           -.130            .077
      60            .070           -.129            .054
      70            .070           -.124            .032
      80            .070           -.115            .011
      90            .070           -.103           -.008
     100            .070           -.088           -.025
     110            .070           -.070           -.039
     120            .070           -.050           -.049
     130            .070           -.029           -.056
     140            .070           -.006           -.059
     150            .070            .016           -.058
     160            .070            .038           -.053
     170            .070            .059           -.045
     180            .070            .078           -.033
     190            .070            .095           -.018
     200            .070            .109            .000
     210            .070            .120            .020
     220            .070            .126            .042
     230            .070            .130            .064
     240            .070            .129            .087
     250            .070            .124            .109
     260           -.930            .020            .126
     270           -.930           -.156            .115
     280           -.930           -.335            .672
     290           -.930           -.503           -.001
     300           -.930           -.657           -.103
     310           -.930           -.790           -.230
     320           -.930           -.900           -.378
     330           -.930           -.982           -.542
```

```
            ************************************
            *  CALCULATION OF NOZZLE STRENGTH  *
            ************************************

              UNIT CONCENTRATED AXIAL LOAD CASE

           NOZZLE FOUNDATION ANGLE (DEGREES)= 360
```

$\beta = 0.9$

```
     REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

 Fd          Va        Ma         Ta         Vb         Mb         Tb
 180        .500     -.302      1.000      -.500      -.302     -1.000


        TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

       X              V                 M                T
       0            .500              -.302            1.000
      15            .500              -.421             .905
      30            .500              -.511             .782
      45            .500              -.567             .640
      60            .500              -.584             .489
      75            .500              -.561             .338
      90            .500              -.500             .198
     105            .500              -.405             .079
     120            .500              -.282            -.011
     135            .500              -.140            -.067
     150            .500               .011            -.084
     165            .500               .162            -.061
     180            .500               .302             .000
     195           -.500               .162             .061
     210           -.500               .011             .084
     225           -.500              -.140             .067
     240           -.500              -.282             .011
     255           -.500              -.405            -.079
     270           -.500              -.500            -.198
     285           -.500              -.561            -.338
     300           -.500              -.584            -.489
     315           -.500              -.567            -.640
     330           -.500              -.511            -.782
     345           -.500              -.421            -.905
     360           -.500              -.302           -1.000
```

CANADIAN MARINE DRILLING LIMITED

STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE: **Program "NOZ-5B:F8" Listing**

APPENDIX A

```
**************************************
*  CALCULATION OF NOZZLE STRENGTH  *
**************************************

UNIT CONCENTRATED AXIAL LOAD CASE

NOZZLE FOUNDATION ANGLE (DEGREES)= 360
```

$\beta = 20$

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

 Fd          Va          Ma          Ta          Vb          Mb          Tb
180         .500       -.606       1.000       -.500       -.606      -1.000


TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

     X             V              M             T
     0           .500          -.606          1.000
    10           .500          -.684           .887
    20           .500          -.741           .762
    30           .500          -.775           .630
    40           .500          -.786           .493
    50           .500          -.773           .357
    60           .500          -.736           .225
    70           .500          -.677           .101
    80           .500          -.598          -.010
    90           .500          -.500          -.106
   100           .500          -.387          -.184
   110           .500          -.262          -.241
   120           .500          -.130          -.275
   130           .500           .007          -.286
   140           .500           .143          -.273
   150           .500           .275          -.236
   160           .500           .399          -.177
   170           .500           .510          -.098
   180           .500           .606          -.000
   190          -.500           .510           .098
   200          -.500           .399           .177
   210          -.500           .275           .236
   220          -.500           .143           .273
   230          -.500           .007           .286
   240          -.500          -.130           .275
   250          -.500          -.262           .241
   260          -.500          -.387           .184
   270          -.500          -.500           .106
   280          -.500          -.598           .010
   290          -.500          -.677          -.101
   300          -.500          -.736          -.225
   310          -.500          -.773          -.357
   320          -.500          -.786          -.493
   330          -.500          -.775          -.630
   340          -.500          -.741          -.762
   350          -.500          -.684          -.887
   360          -.500          -.606         -1.000
```

```
**************************************
*  CALCULATION OF NOZZLE STRENGTH   *
**************************************

UNIT CONCENTRATED AXIAL LOAD CASE


NOZZLE FOUNDATION ANGLE (DEGREES)= 360
```

$\beta=0.9$

```
REACTIONS,BENDING AND TWISTING MOMENTS AT NOZZLE FOUNDATIONS

  Fd        Va        Ma        Ta        Vb        Mb        Tb
 270      .091      .099      .250     -.909     -.901     -.750


TRANSVERSE SHEAR,BENDING AND TWISTING MOMENT ALONG NOZZLE

      X                 V                 M                 T
      0               .091              .099              .250
     15               .091              .055              .270
     30               .091              .006              .270
     45               .091             -.042              .274
     60               .091             -.088              .256
     75               .091             -.128              .228
     90               .091             -.159              .190
    105               .091             -.179              .145
    120               .091             -.187              .097
    135               .091             -.183              .048
    150               .091             -.166              .003
    165               .091             -.137             -.037
    180               .091             -.099             -.060
    195               .091             -.055             -.089
    210               .091             -.006             -.097
    225               .091              .042             -.092
    240               .091              .088             -.075
    255               .091              .128             -.046
    270               .091              .159             -.008
    285              -.909             -.079              .002
    300              -.909             -.313             -.049
    315              -.909             -.524             -.160
    330              -.909             -.701             -.321
    345              -.909             -.829             -.522
    360              -.909             -.901             -.750
```

9. PROGRAM "FORCES" LISTING

```
10    ! PROGRAM TO CALCULATE SECTION PROPERTIES,K-FACTORS AND FORCES TO CAUSE
20    ! YIELD:"FORCES"
30    ! PROGRAM:"FORCES";UPDATED 21/09/84
40    ! DECLARE VARIABLES
50    REAL L,D,T1,T2,N,Sy
60    FIXED 3
70 Main:   !
80    GOSUB Input
90    GOSUB Sections
100   GOSUB K_factors
110   GOSUB Forces
120   GOSUB Area
130   GOSUB Print_results
140   STOP
150   END
160 Input:!
170   INPUT "ENTER: RADIUS TO NOZZLE AXIS (CM)",R
180   INPUT "ENTER: LENGTH OF NOZZLE (Cm)",L
190   INPUT "ENTER: DEPTH OF NOZZLE (Cm)",D
200   INPUT "ENTER: THICKNESS OF SHELL (Cm)",T1
210   INPUT "ENTER: THICKNESS OF WEBS (Cm)",T2
220   INPUT "ENTER: NUMBER OF WEBS",N
230 ! INPUT "ENTER: TOTAL CROSS-SECTIONAL AREA (Cm)",A
240 ! INPUT "ENTER: SHEAR AREA (Cm^2)",As
250   INPUT "ENTER: SECTION MODULUS (Cm^3)",Sm
260   INPUT "ENTER: YIELD STRESS (Kg/Cm^2)",Sy
270 ! INPUT "Rc",Rc
280 ! INPUT "Bc",Bc
290 ! INPUT "Tc",Tc
300   RETURN
310 Sections:  !
320   As=N*T2*D                     !SHEAR AREA
330   A=As+2*L*T1                   !TOTAL AREA
340 ! Sm=L*T1*D+N*T2*D^2/6          !SECTION MODULUS
350 ! I=L*T1*D^2/2+N*T2*D^3/12      !INERTIA
360   RETURN
370 K_factors:  !
380  ! Hc=H/C
390   Tc=T1*2/D
400   Rc=R*2/D
410   Bc=T2*N/L
420  ! IC=I/(A*C^2)
430   Hc=Rc-2*(Tc+(1-Tc)*Bc)/(LOG((Rc^2+(Rc+1)*Tc-1)/(Rc^2-(Rc-1)*Tc-1))+Bc*LOG(
(Rc-Tc+1)/(Rc+Tc-1)))
440   Ic=(1-(1-Bc)*(1-Tc)^3)/(3*(1-(1-Bc)*(1-Tc)))
450   Ki=Ic/(Rc-1)*(1-Hc)/Hc
460   Ko=Ic/(Rc+1)*(1+Hc)/Hc
470   RETURN
480 Forces:  !
490   ! FOR NOZZLE FOUNDATION HALF-ANGLE=165 DEGREES
500   Ftf=A*Sy/.679
510   Fsf=As*.577*Sy/.864
520   Fbm=Sm*Sy/(.577*Ki*R)
530   Fmin=MIN(Ftf,Fsf,Fbm)
540   F=Fmin*9.81/10^6     ! CONVERTING FORCE IN MN
550   RETURN
560 Area:  !
570   Afm=-2.075010E-7*F^5+1.993357E-5*F^4-5.095297E-4*F^3+7.052402E-3*F^2+4.314
002E-2*F+6.351200E-5
580   Afc=Afm*10^4
590   RETURN
600 Print_results:  !
610   PRINT "RADIUS TO NOZZLE AXIS=";R;"Cm"
620   PRINT "NOZZLE LENGTH=";L;"Cm"
630   PRINT "NOZZLE DEPTH=";D;"Cm"
640   PRINT "THICKNESS OF SHELL=";T1;"Cm"
```

```
650   PRINT "THICKNESS OF WEB=";T2;"Cm"
660   PRINT "NUMBER OF WEBS=";N
670   PRINT "YIELD STRESS=";Sy;"N/Cm^2"
680   PRINT LIN(3)
690   PRINT "SHEAR AREA=";As;"Cm^2"
700   PRINT "TOTAL AREA=";A;"Cm^2"
710   PRINT "SECTION MODULUS=";Sm;"Cm^3"
720   PRINT "INERTiA=";Sm*D/2;"Cm^4"
730   PRINT LIN(2)
740 ! PRINT "R/C=";Rc
750 ! PRINT "H/C=";Hc
760   PRINT "Ki=";Ki
770   PRINT "Ko=";Ko
780   PRINT LIN(2)
790   PRINT TAB(20);"MAXIMUM POINT LOAD CAUSING YIELD (TONNES)"
800   PRINT LIN(1);TAB(15);"COMPRESSION";TAB(40);"SHEAR";TAB(58);"BENDING"
810   IMAGE 17X,MDDDDD,14X,MDDDDD,14X,MDDDDD
820   PRINT USING 810;Ftf/1000;Fsf/1000;Fbm/1000
830   PRINT LIN(2);TAB(24);"LIMITING FORCE/AREA RELATIONSHIP"
840   PRINT LIN(1);TAB(22);"LIMITING FORCE ";TAB(54);"AREA "
850   PRINT TAB(25);"(Tonnes)";TAB(53);"(Cm^2)"
860   IMAGE 23X,MDDDDD,20X,MDDDDDD
870   PRINT USING 860;Fmin/1000;Afc
880   RETURN
```

PROGRAM "FORCES"

SAMPLE OUTPUT

```
66      PRINT "H/C=";Hc
67      PRINT "Ki=";Ki
68      PRINT "Ko=";Ko
690     PRINT LIN(2)
700     PRINT TAB(20);"MAXIMUM POINT LOAD CAUSING YIELD (TONNES)"
710     PRINT LIN(1);TAB(15);"COMPRESSION";TAB(40);"SHEAR";TAB(58);"BENDING"
720     IMAGE 17X,MDDDDD,14X,MDDDDD,14X,MDDDDD
730     PRINT USING 720;Ftf/1000;Fsf/1000;F   1000
740     RETURN
```

```
RA       TO NOZZLE AXIS= 220.000 Cm
NO        LENGTH= 200.000 Cm
NO        DEPTH= 40.000 Cm
TH        SS OF SHELL= 2.500 Cm
TH       ESS OF WEB= 2.500 Cm
NU         F WEBS= 4.000
YI       STRESS= 3600.000 N/Cm^2



SHE    AREA= 400.000 Cm^2
TOT    AREA= 1400.000 Cm^2
SE      N MODULUS= 22667.000 Cm^3
IN     IA= 453340.000 Cm^4


Ki= 1.027
Ko=  976


                    MAXIMUM POINT LOAD CAUSING YIELD (TONNES)

               COMPRESSION              SHEAR             BENDING
                  7423                   962                 626
```

APPENDIX B

FEM PROGRAM DOCUMENTATION

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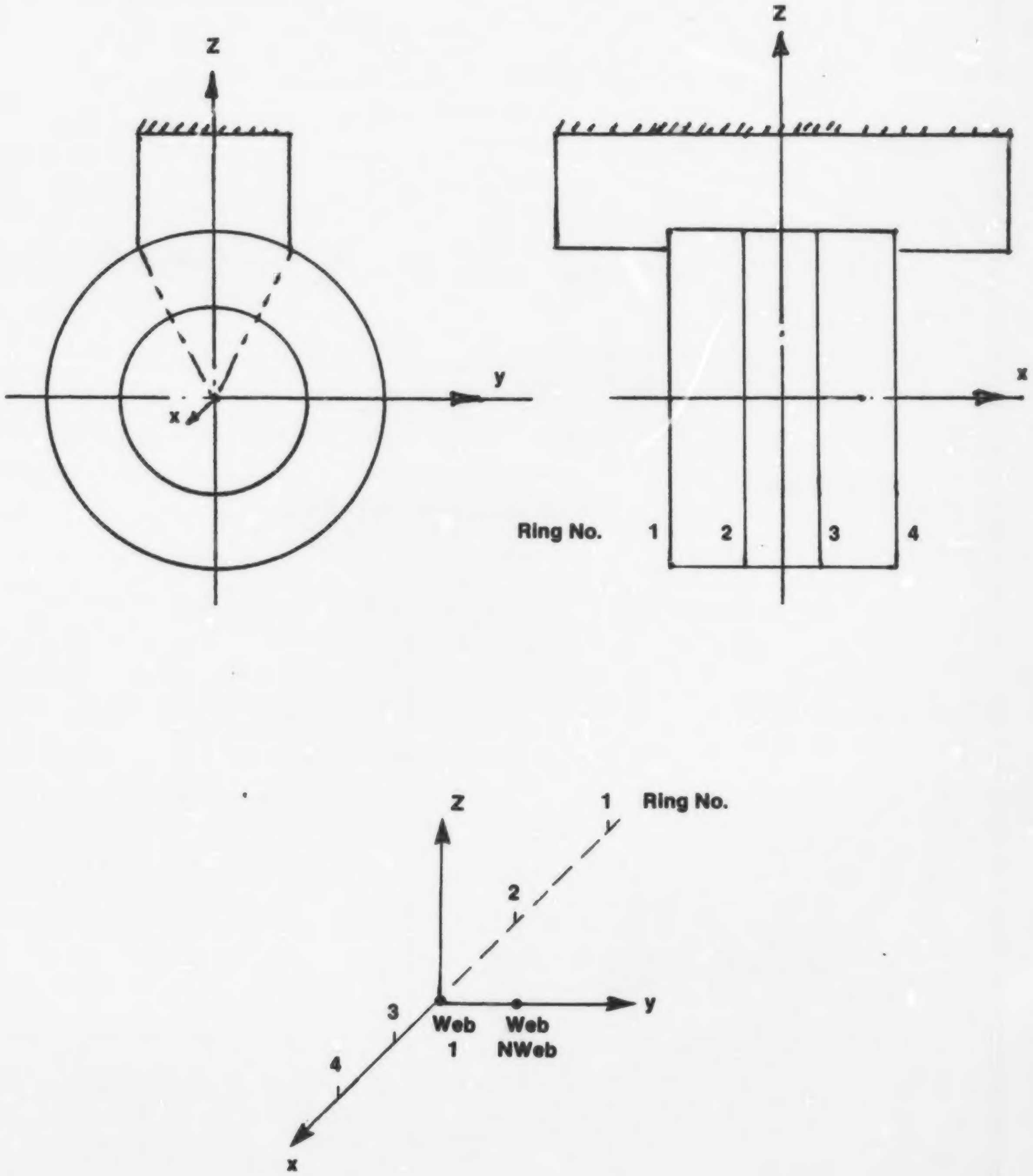
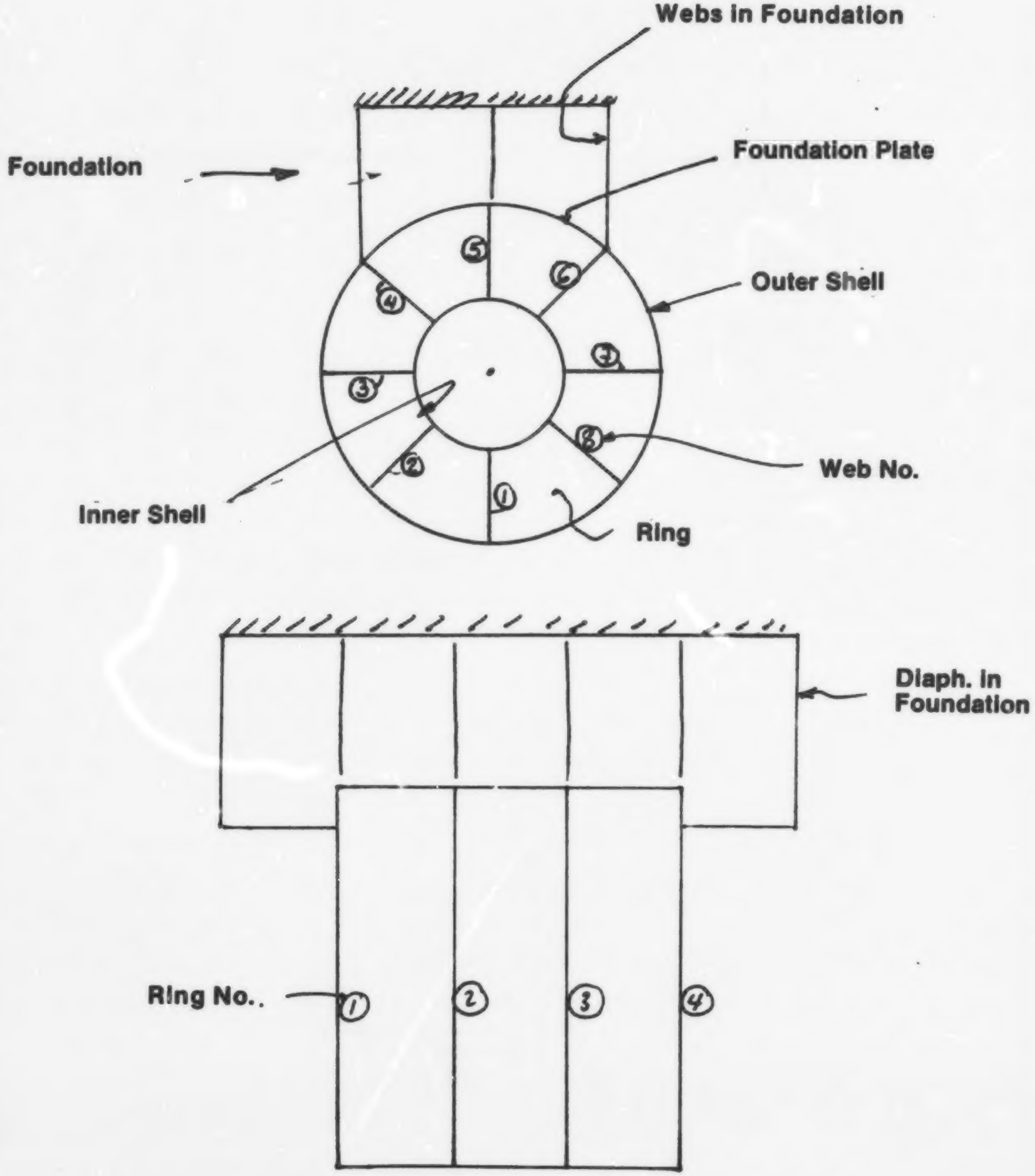

z
y
x
z
x
Ring No. 1 2 3 4
Z
1 Ring No.
2
y
3
4
Web 1
Web NWeb
x

CANADIAN MARINE DRILLING LIMITED

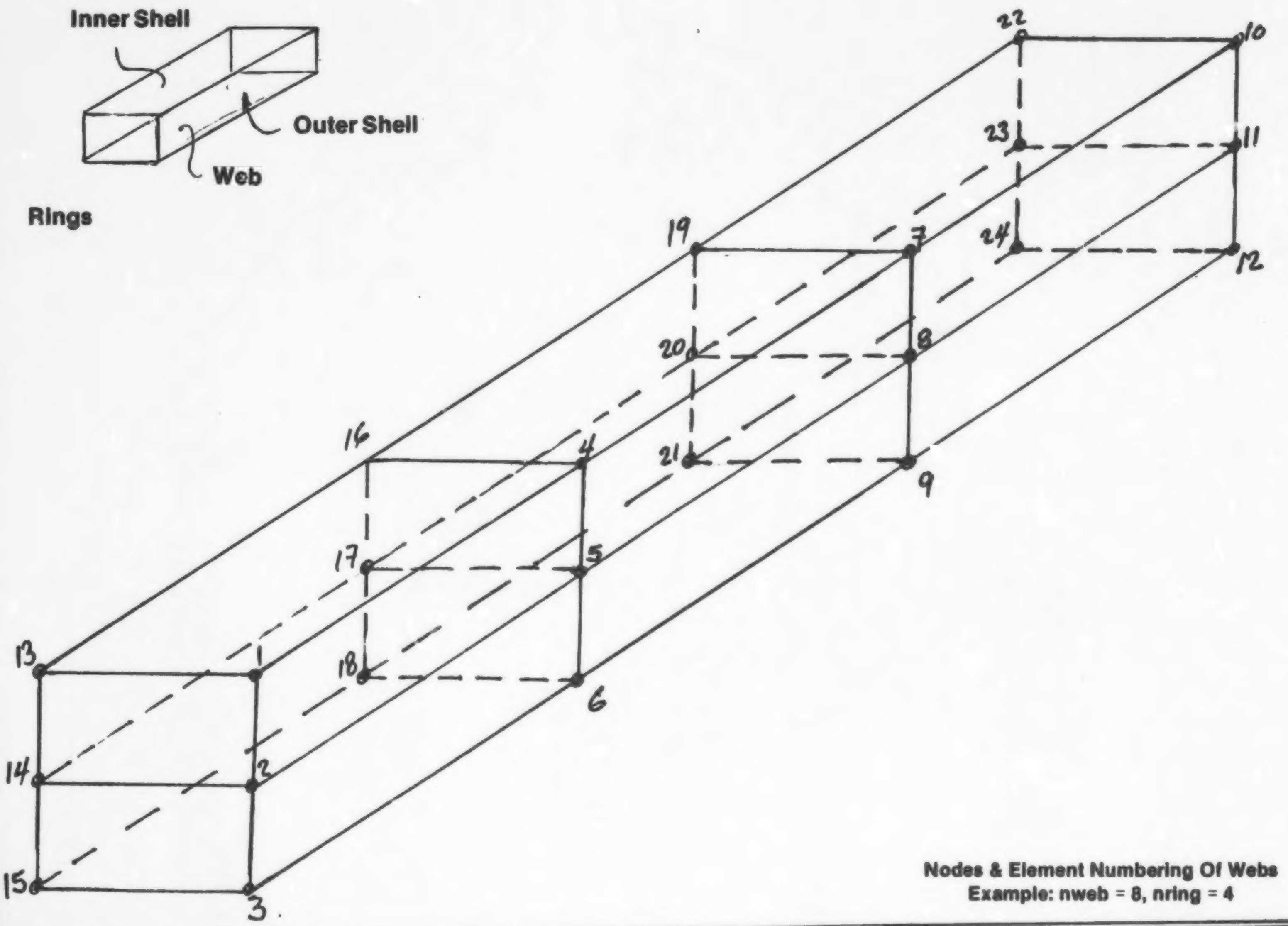
STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE: **FEM Reference Axes**

FIGURE No. B1

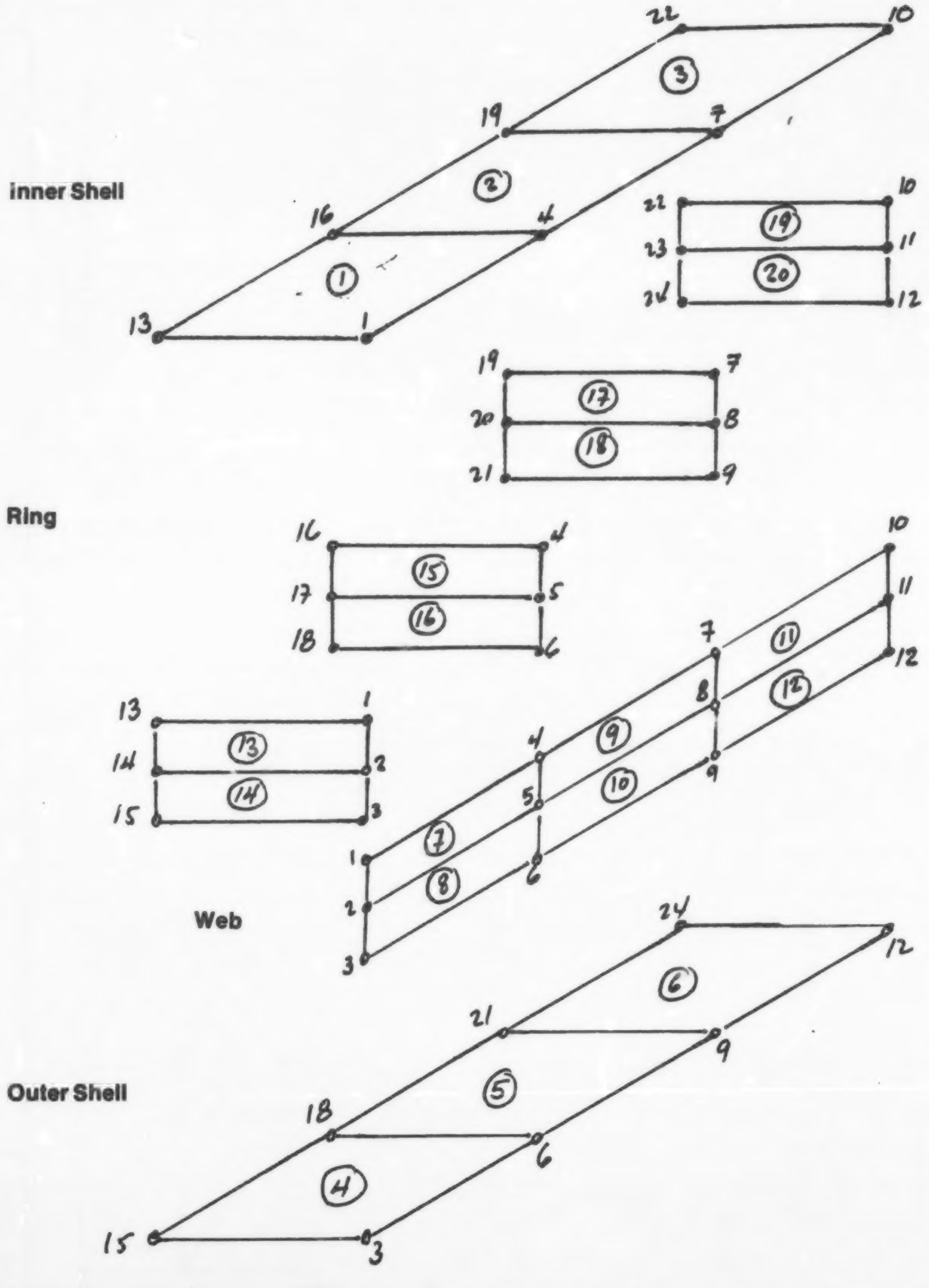

Webs in Foundation
Foundation
Foundation Plate
5
6
4
Outer Shell
7
3
8
Web No.
2
1
Inner Shell
Ring
Diaph. in Foundation
Ring No..
1
2
3
4

CANADIAN MARINE DRILLING LIMITED	STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS	TITLE: Definition Of Nozzle Structure FIGURE No. B2


Inner Shell
Outer Shell
Web
Rings
13
14
15
1
2
3
16
17
18
4
5
6
19
20
21
7
8
9
22
23
24
10
11
12

Nodes & Element Numbering Of Webs
Example: nweb = 8, nring = 4

CANADIAN MARINE DRILLING LIMITED	STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS	TITLE: 1st Segment Node Numbering
		FIGURE No. B3

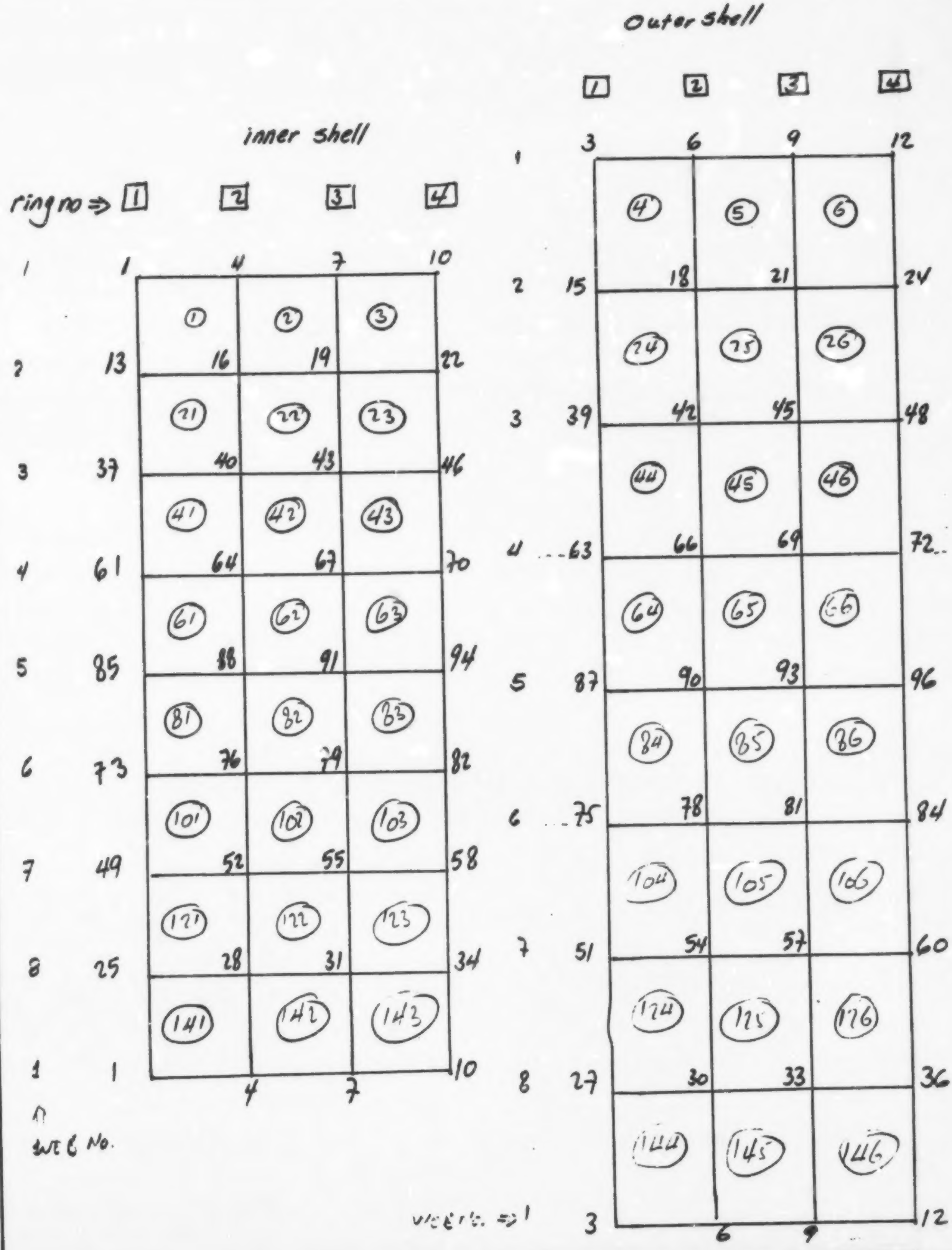

22
10
③
19
7
Inner Shell
②
16
4
①
13
1
22
10
⑲
23
11
⑳
24
12
19
7
⑰
20
8
⑱
21
9
Ring
16
4
⑮
17
5
⑯
18
6
10
11
⑪
12
7
8
⑫
13
1
⑬
14
2
⑭
15
3
4
⑨
5
⑩
9
1
⑦
2
⑧
6
3
Web
24
12
⑥
21
9
⑤
Outer Shell
18
6
④
15
3

CANADIAN MARINE DRILLING LIMITED

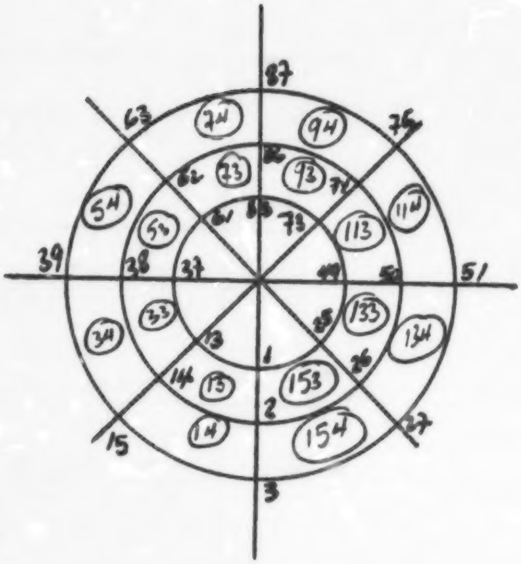
STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS

TITLE: Nodes And Element Numbering

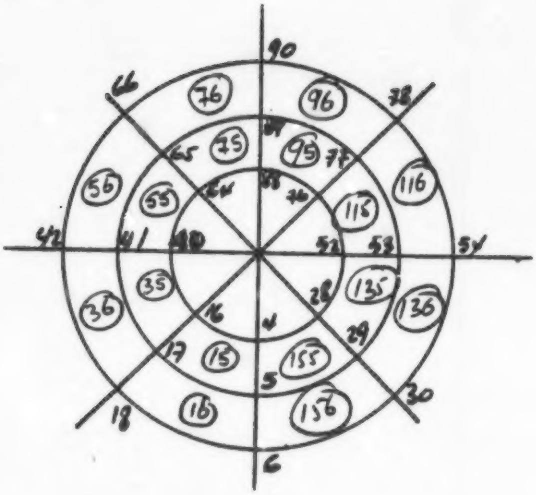
FIGURE No. B4


Outer shell
1
2
3
4
inner shell
ring no ⇒
1
2
3
4
1 1 4 7 10
① ② ③
2 13 16 19 22
(21) (22) (23)
3 37 40 43 46
(41) (42) (43)
4 61 64 67 70
(61) (62) (63)
5 85 88 91 94
(81) (82) (83)
6 73 76 79 82
(101) (102) (103)
7 49 52 55 58
(121) (122) (123)
8 25 28 31 34
(141) (142) (143)
1 1 4 7 10
web No.
1 3 6 9 12
④ ⑤ ⑥
2 15 18 21 24
(24) (25) (26)
3 39 42 45 48
(44) (45) (46)
4 63 66 69 72
(64) (65) (66)
5 87 90 93 96
(84) (85) (86)
6 75 78 81 84
(104) (105) (106)
7 51 54 57 60
(124) (125) (126)
8 27 30 33 36
(144) (145) (146)
web no. ⇒ 1 3 6 9 12

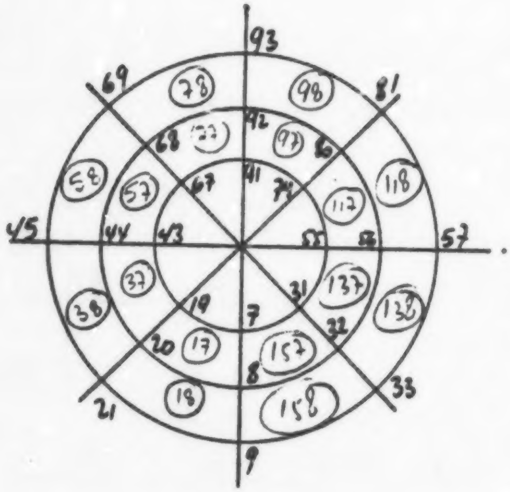
CANADIAN MARINE DRILLING LIMITED	STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS	TITLE: Node & Element Numbering (Inner and Outer Shell)
		FIGURE No. B5


87
63
74
94
75
54
62
73
86
93
76
114
53
61
85
73
113
39
38
37
49
50
51
34
33
13
25
133
134
14
13
1
26
153
2
27
15
14
154
3

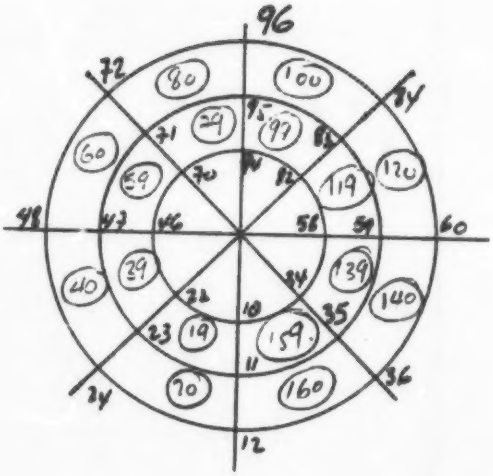
RING NO. 1


90
66
76
96
78
65
75
89
95
77
56
55
64
88
76
115
116
42
41
40
52
53
54
36
35
16
4
28
135
136
17
15
155
29
5
18
16
156
30
6

RING NO. 2


93
69
78
98
81
68
77
92
97
80
58
57
67
91
79
117
118
45
44
43
55
56
57
37
38
19
7
31
137
138
20
17
157
32
8
21
18
158
33
9

RING NO. 3


96
72
80
100
84
71
79
95
99
83
60
59
70
94
82
119
120
48
47
46
58
59
60
39
40
22
10
34
139
140
23
19
159
35
11
24
20
160
36
12

RING NO. 4

Nodes & Element Numbering of Rings
Example: nweb = 8, nring = 4

CANADIAN MARINE DRILLING LIMITED	STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS	TITLE: Nodes and Element Numbering (Rings and Webs) FIGURE No. B7

DEFINITIONS OF VARIABLE USED

NRING = total number of rings

ANGW = angle between any two webs in degrees
a full circle (360°) must be a multiple of this angle
NWEB = total number of webs
= (360 + 0.0001)/ANGW
Check/NWEB* ANGW - 360/ ≤ 0.0001
Error No. 1

RADIS = radius of inner shell

ARDIO = A radial distance between inner and outer shells

BR(i) = distance between rings in x - direction from the most negative to most positive x - direction (i=1, nring=1)

ANGF = angle between negative Z - axis and outer foundation plate in degrees, assumed symmetrical about z - axis and ANGW must be multiple of ANGF

NWEBF = total number of webs between foundation plate
= 2 (ANGF + 0.0001)/ANGW +1
/(NWEBF - 1) ANGW - 2 ANGF/ ≤ 0.001 Error No. 2

NWFS = number of web where foundation start
= (180 - ANGF + 0.0001)/ANGW + 1

DEFINITION OF DIMENSIONS

EFOUN = distance of extension of foundation in x - direction (symmetrical)

HFOUN = height of foundation

NXF = total numbers of divisions in x - direction for EFOUN

NZF = total numbers of divisions in z - direction for HFOUN

NWF = total numbers of webs in foundation

NTHIC = total number of different thickness for webs, rings, diaph. in foundation and webs in foundation

DEFINITION OF THICKNESSES

THIS = thickness of inner shell

THOS = thickness of outer shell outside foundation lines

THFP = thickness of foundation plate includes outer shell between foundation lines

ITHR(i) = thickness of each ring (I=1, NRJUC)

ITHD(i) = thickness type number for diaphragms from last x - negative to x - positive (i=1, nring+2) ie. left diaphragms, ring no. 1, ring no. nring, right diaphragm

ITHWF(i) = thickness type number for webs in the foundation (i=1, NWF)

ITHW = (j, i) j = 1, 3 & i - 1, to max NWEB (NITHW)
j = 1 is thickness from web number
j = 2 is thickness to web number
j = 3 is thickness type

THICK(i) = value of thicknesses (i=1, NTHIC)

See Example on Page B20

THFPI = thickness of foundation plate of inner shell between foundation line

NPRG = total number of nodes in all rings

NERG = total number of elements in all rings

NPOIN = total number of nodes in structure

NELEM = total number of elements in structure

NBOT = total number of nodes in all rings and foundation plate

NEBOT = total number of elements in all rings and foundation plate

NADF = total number of nodes in any x-y plane in foundation

NPRG = 3* NWEB* NRING

NERG = (6*NRING - 4) NWEB

NBOT = NPRG + 2*N x F* NWEBF

NADF = NWEBF *(2 + NRING) + 2* NWF * (N x F - 1)

NEBOT = NERG + 2(NWEBF - 1)N x F

NPOIN = NBOT + NADF * NZF

NELEM = NEBOT + (NWEBF - 1)(2 + NRING) NZF +(2NXF + NRING - 1)x NZF x NWF

DOME PETROLEUM LIMITED

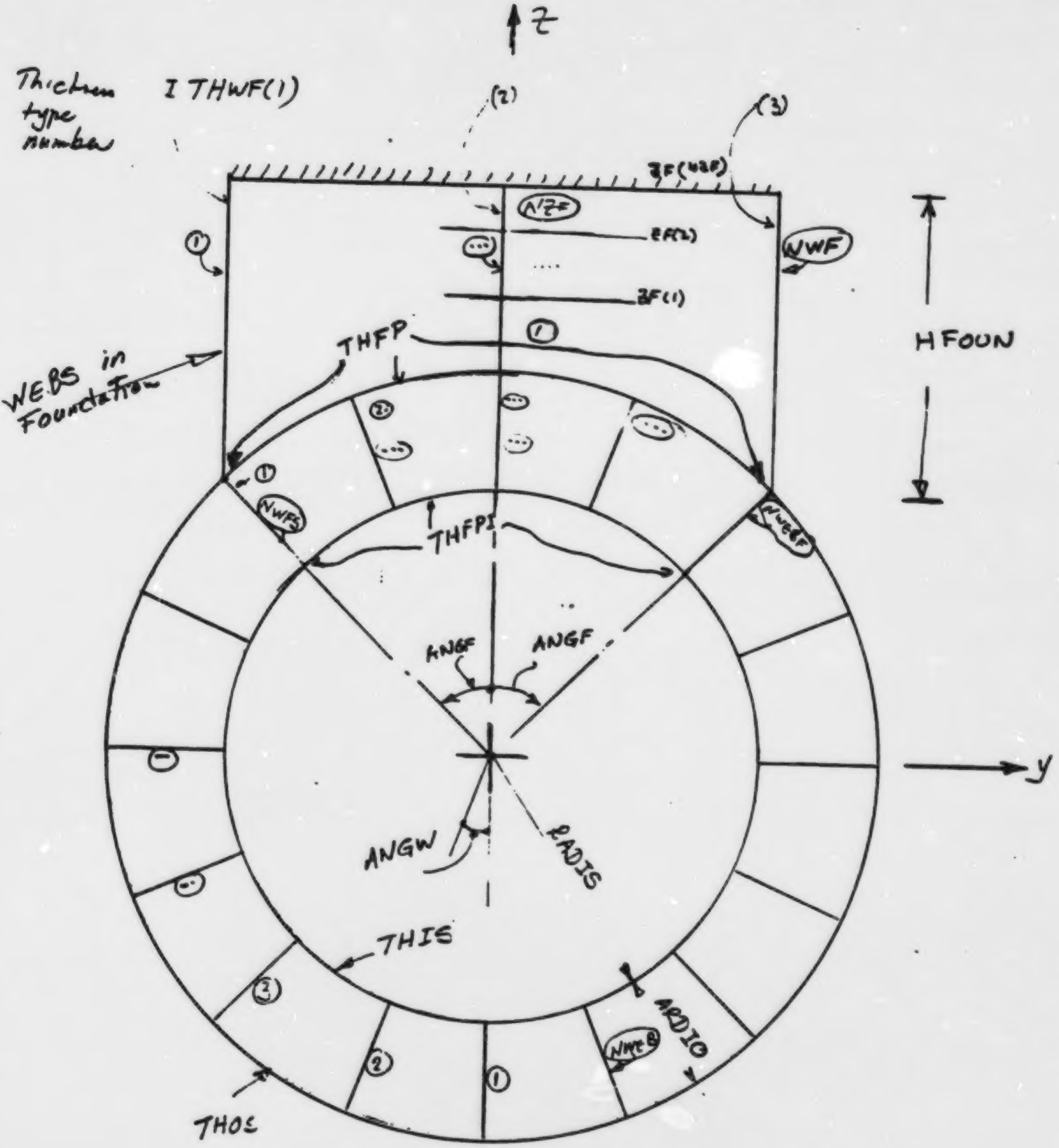
CALCULATION SHEET

TITLE PROJECT Nozzle definition

DATE

PREPARED BY

CHECKED BY



Z
Thickness type number
I THWF(1)
(2)
(3)
ZF(NZF)
NZF
ZF(2)
(...)
....
ZF(1)
①
NWF
HFOUN
THFP
WEBS in Foundation
②
(...)
NWFS
NWGF
THFPI
ANGF
ANGF
ANGW
RADIS
y
THIS
③
②
①
NWEB
RADIO
THOS

DOME PETROLEUM LIMITED

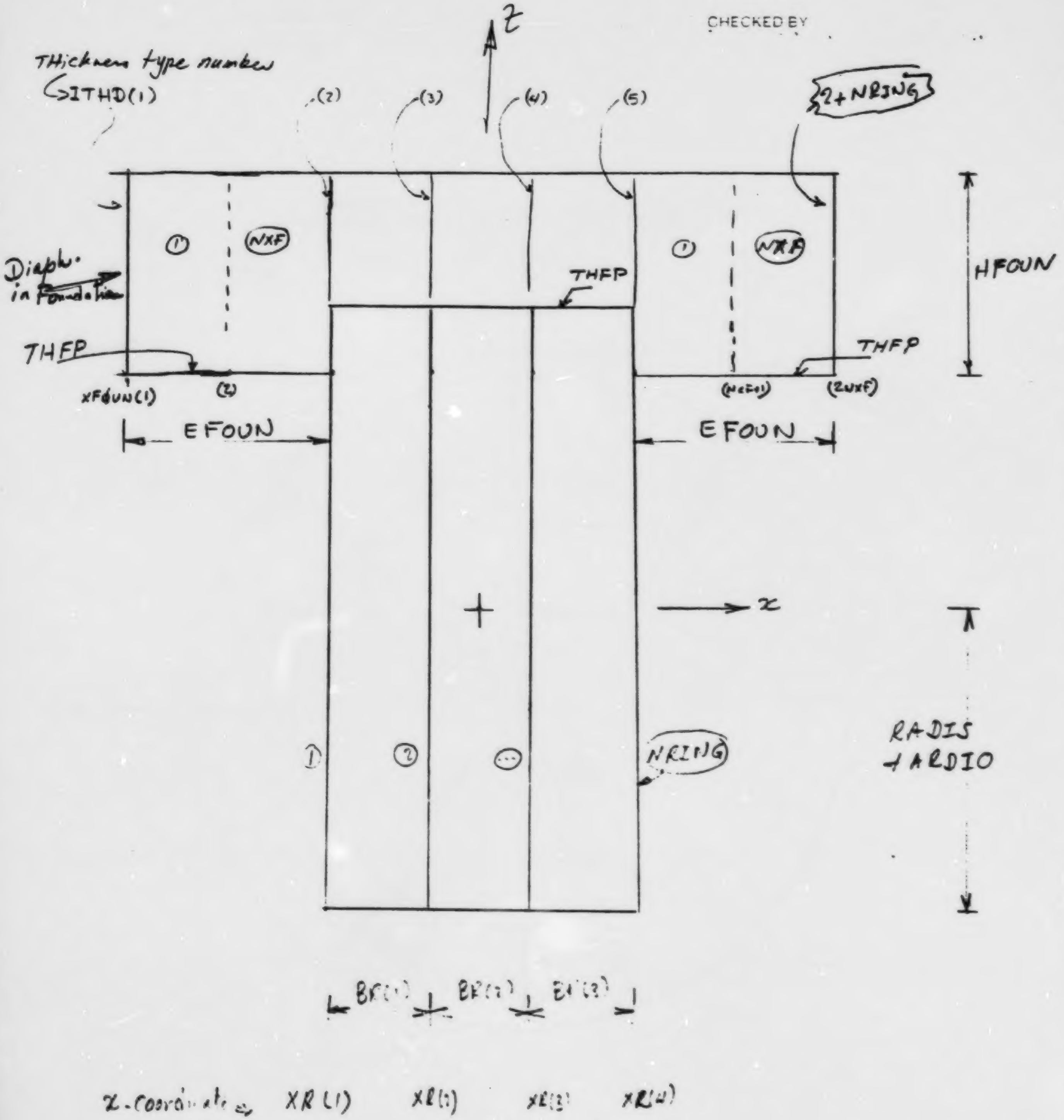
CALCULATION SHEET

TITLE PROJECT Nozzle definitions.

DATE

PREPARED BY

CHECKED BY


z
Thickness type number
ITHD(1)
(2)
(3)
(4)
(5)
2+NRING
①
NXF
①
NXF
Diaph. in Foundation
THFP
THFP
THFP
HFOUN
xFOUN(1)
(2)
(NXF+1)
(2NXF)
EFOUN
EFOUN
x
①
②
…
NRING
RADIS + ARDIO
BR(1)
BR(2)
BR(3)
x-coordinates XR(1)
XR(2)
XR(3)
XR(4)

B 14

PAGE of

DOME PETROLEUM LIMITED

CALCULATION SHEET

DATE

TITLE PROJECT WEB NUMBERING

PREPARED BY

CHECKED BY

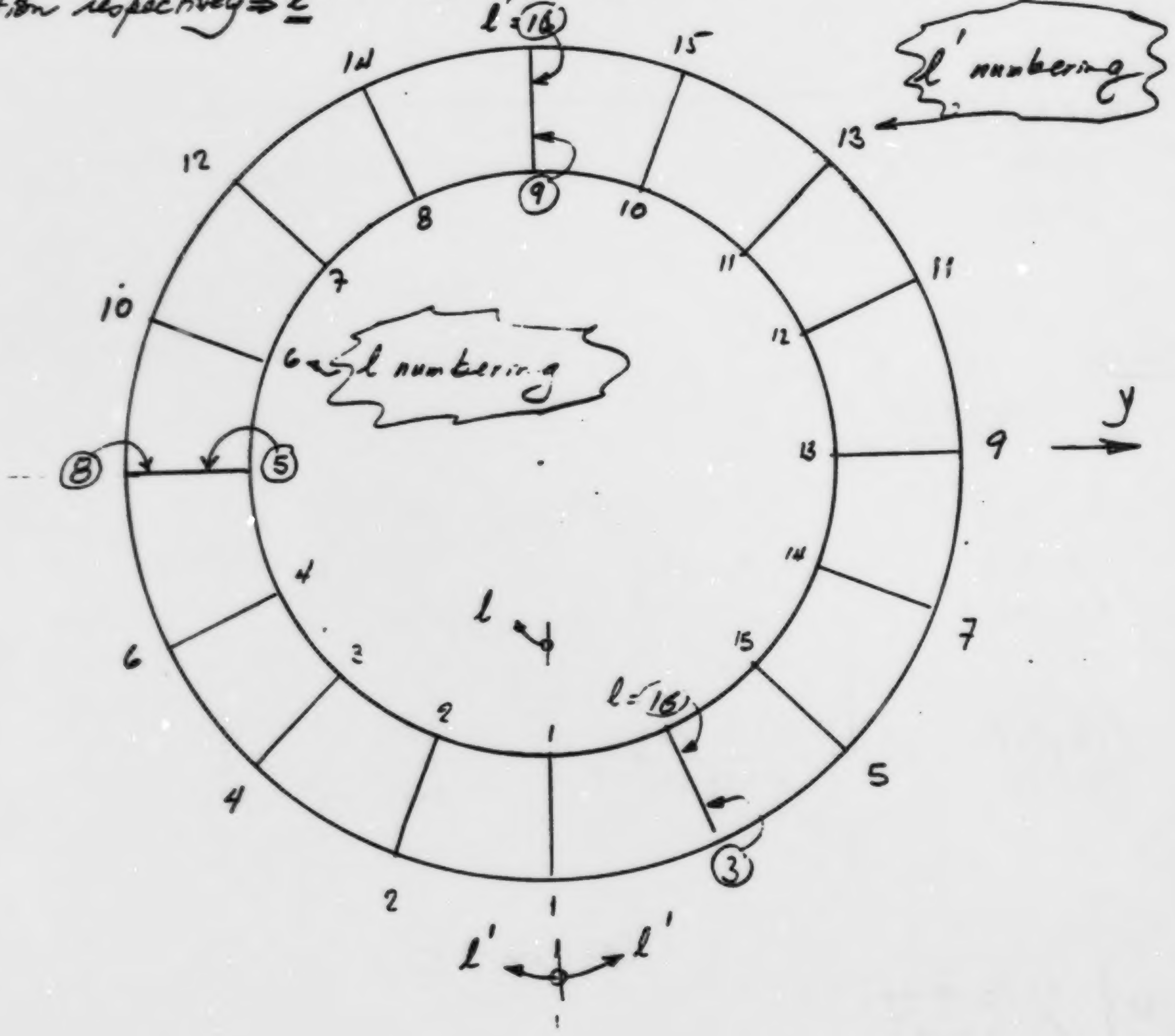
WEB numbering

z

l ⇒	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
l' ⇒	1	2	4	6	8	10	12	14	16	15	13	11	9	7	5	3

Array IWEB

- Array IWEB relates two different numbering system for webs.
- l ⇒ Index of IWEB is the numbering stystem of webs in clockwise direction ⇒ l
- l' ⇒ Value of IWEB is the numbering stystem of webs in clockwise, anticlockwise direction respectively ⇒ l'



l' = 16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
l' numbering
9
8
10
7
11
12
6
l numbering
5
13
14
4
3
15
l = 16
2
1
y
l
l'
l'

PROJECT

Nodes & Element Numberings for Inner shell

DATE

PREPARED BY

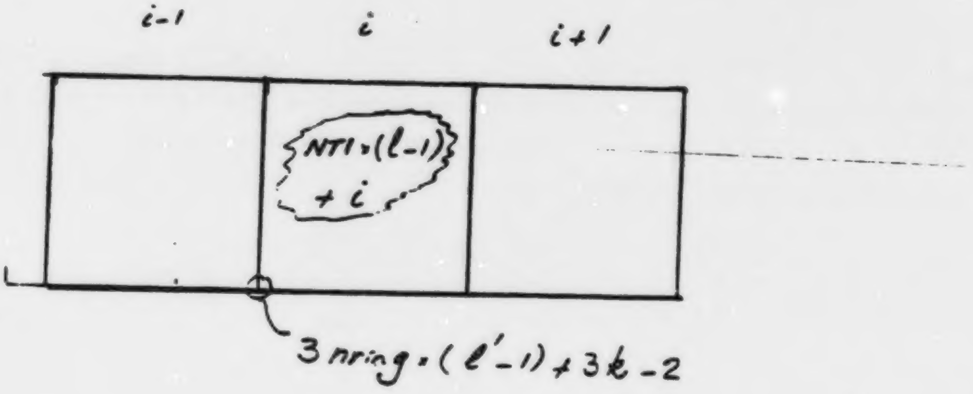
CHECKED BY

$NTI = 6\,nring - 4$

Ring No. ⇒ $k = i-1$ $k = i$ $k = i+1$ $k = i+2$

WEB No. l
use IWEB to get l'

WEB No. $l+1$
use IWEB to get l'
IF $l+1 >$ NWEB
use $l = l' = 1$


$i-1$
i
$i+1$
$NTI \times (l-1) + i$
$3\,nring \times (l'-1) + 3k - 2$

IWEB.

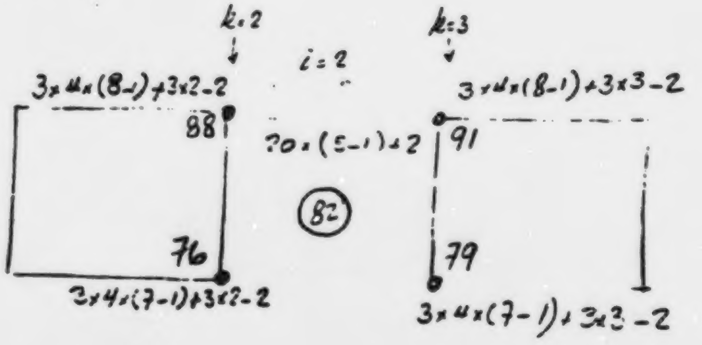
$l =$	1	2	3	4	5	6	7	8
$l' =$	1	2	4	6	8	7	5	3

SEE page 13

Example $i = 2$ & web No. $l = 5$
$nring = 4$
$NTI = 6 \times 4 - 4 = 20$

$l = 5$, $l' = 8$
from IWEB

$l = 6$, $l' = 7$
from IWEB


$k=2$
$i=2$
$k=3$
$3 \times 4 \times (8-1) + 3 \times 2 - 2$
$3 \times 4 \times (8-1) + 3 \times 3 - 2$
88
$20 \times (5-1) + 2$
91
82
76
79
$3 \times 4 \times (7-1) + 3 \times 2 - 2$
$3 \times 4 \times (7-1) + 3 \times 3 - 2$

SEE page 5

$\longrightarrow \begin{cases} i = 1, nring-1 \\ l = 1, nweb \end{cases}$

DOME PETROLEUM LIMITED

CALCULATION SHEET

TITLE PROJECT

Nodes & Elements Numberings for Outer shell

DATE

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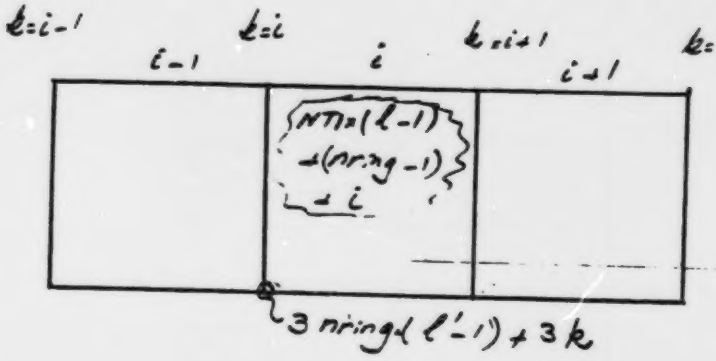
NT1 = 6 nring − 4

Ring No. ⇒

WEB No. l
USE IWEB to get l'


k=i−1
k=i
k=i+1
k=i+2
i−1
i
i+1
NT1×(l−1)
+(nring−1)
+i
3 nring(l'−1) + 3k

WEB No. l+1
USE IWEB to get l'
if l+1 > NWEB
USE l=l'=1

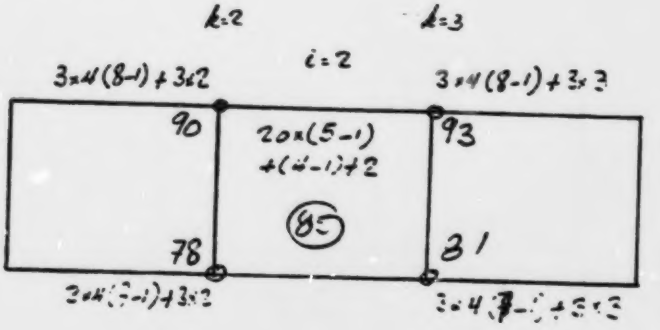
	l ⇒	1	2	3	4	5	6	7	8
IWEB	l' ⇒	1	2	4	6	8	7	5	3

SEE page 13

Example i=2 & WEB No. l=5
nring = 4 , NT1 = 20

l=5, l'=8

l=6, l'=7


k=2
k=3
i=2
3×4(8−1)+3×2
3×4(8−1)+3×3
90
93
20×(5−1)
+(4−1)+2
85
78
81
3×4(7−1)+3×2
3×4(7−1)+3×3

SEE page 5

→ { i = 1, nring−1
l = 1, nweb

TITLE PROJECT
Nodes & Elements Numberings for Webs.

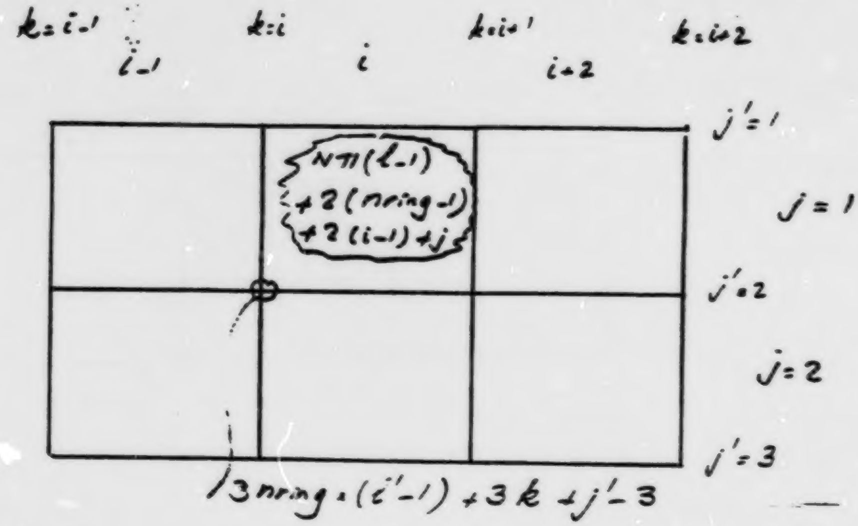
DATE

PREPARED BY

CHECKED BY

$NTI = 6\ nring - 4$

Ring No. ⇒


k=i-1
k=i
k=i+1
k=i+2
i-1
i
i+2
j'=1
NTI(l-1)
+2(nring-1)
+2(i-1)+j
j=1
j'=2
j=2
j'=3
3nring*(i'-1)+3k+j'-3

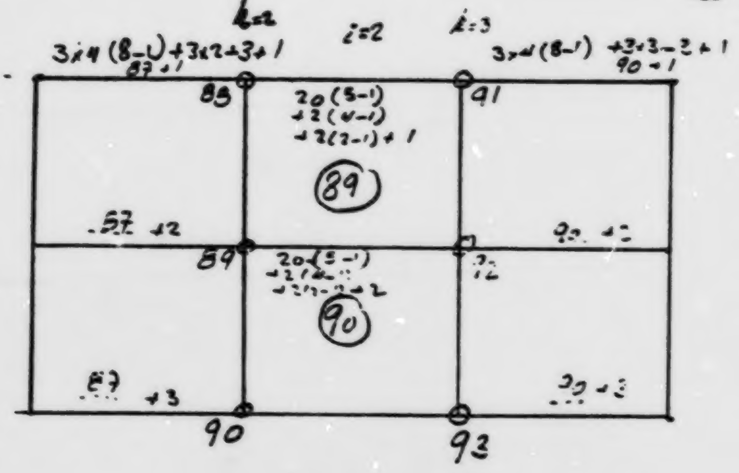
WEB No. l
or use IWEB
to get l'

Example $i=2$, WEB No. 5
$nring=4$, $NTI=20$

$l=5$, $l'=8$

	l ⇒	1	2	3	4	5	6	7	8
IWEB	l' ⇒	1	2	4	6	8	7	5	3

See page 13


k=2
i=2
k=3
3x4(8-1)+3x2-3+1
87+1
3x4(8-1)+3x3-3+1
90+1
88
91
20(5-1)
+2(4-1)
+2(2-1)+1
89
87+2
90+2
89
20(5-1)
+2(4-1)
+2(2-1)+2
92
90
87+3
90+3
90
93

SEE page 6

$$\begin{cases} i = 1, nring-1 \\ j = 1,2 \\ l = 1, nweb \end{cases}$$

B18

TITLE PROJECT DATE

Nodes & Elements Numbering for Rings.

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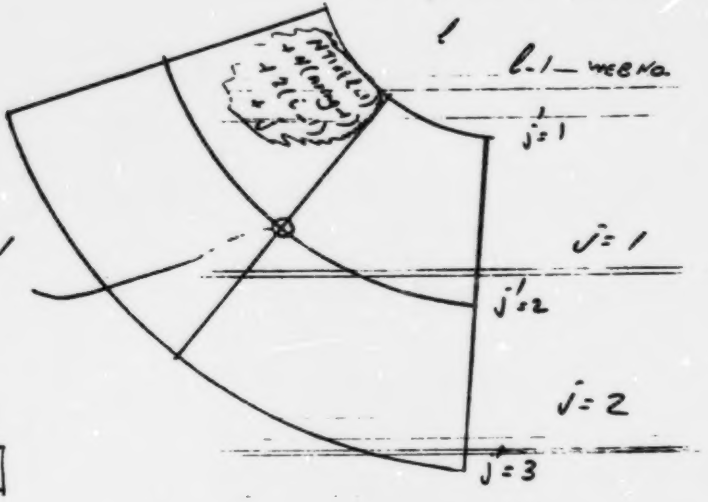
$NT1 = 6\,nring - 4$

i = ring No.

$l = 1$ if $l+1 > NWEB$ use $l = l' = 1$


l
$l-1$ — WEB No.
$NT1 \cdot (l-1) + 4(nring-1) + 2(i-1) + 1$
$j' = 1$
$j = 1$
$j' = 2$
$j = 2$
$j' = 3$

$3\,nring \cdot (l'-1) + 3i - 3 + j'$

	$l \to$	1	2	3	4	5	6	7	8
IWEB	l'	1	2	4	6	8	7	5	3

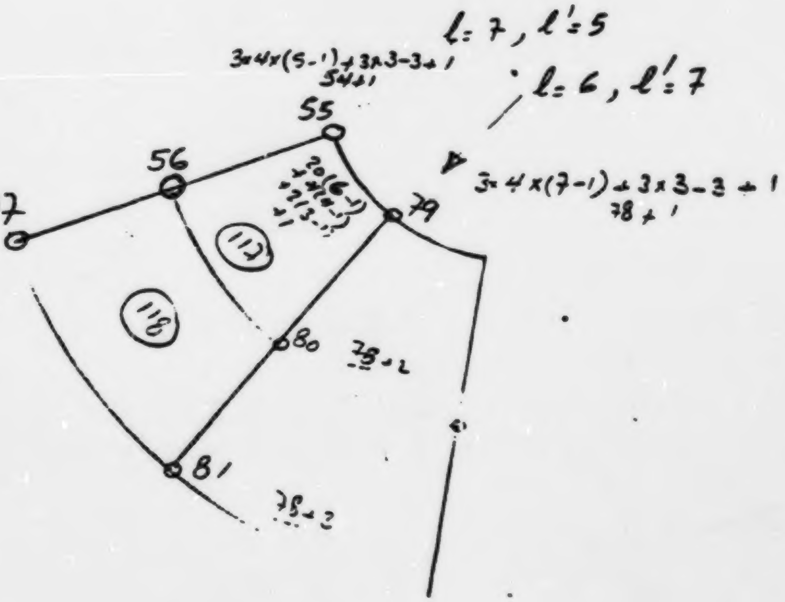
SEE page 13

Example Ring No. 3 & $l = 6$

nring = 4, nt1 = 20

$l' = 7$

SEE Page 7


$l = 7,\ l' = 5$
$3 \times 4 \times (5-1) + 3 \times 3 - 3 + 1$
$54 + 1$
$l = 6,\ l' = 7$
$3 \times 4 \times (7-1) + 3 \times 3 - 3 + 1$
$78 + 1$
55
56
57
79
80
81
$20(6-1) + 4(4-1) + 2(3-1) + 1$
117
118
$78 + 2$
$78 + 3$

$i = 1, nring$
$j = 1, 2$
$l = 1, nweb$

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CALCULATION SHEET

TITLE PROJECT WEBS thickness OFF

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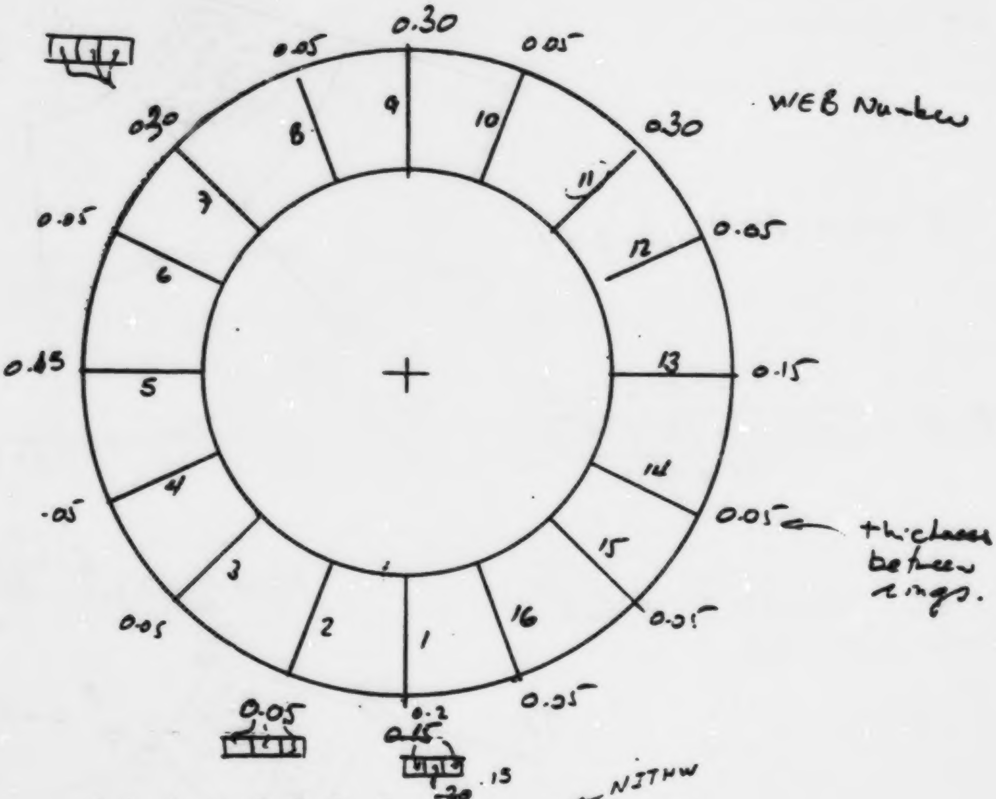
nrng=4


0.30
0.05
0.05
0.30
0.30
WEB Number
0.05
0.05
0.15
0.15
-05
0.05 ← thickness between rings.
0.05
0.05
0.05
0.05
0.2
0.15
.13
.20
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16

INDEX	1	2	3	4	5	6	7	8	9	10	11	12 ← NITHW	
JTHW (1,)	1	2	5	6	7	8	9	10	11	12	13	14	From web
2,)	1	4	5	6	7	8	9	10	11	12	13	16	to web
~~3,)~~	~~1~~	~~2~~	~~1~~	~~2~~	~~3~~	~~2~~	~~3~~	~~2~~	~~3~~	~~2~~	~~1~~	~~2~~	index of ~~JTHW~~
3,)	2	3	1	3	4	3	4	3	4	3	1	3	THICK

JTHW (1)	1	2	1
2)	3	3	3
3)	4	4	4

	1)	2)	3)	4)
THICK	.15	.20	.05	.30

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CALCULATION SHEET

FOUNDATION ~~PLATE~~ DOK (DEFINITION)

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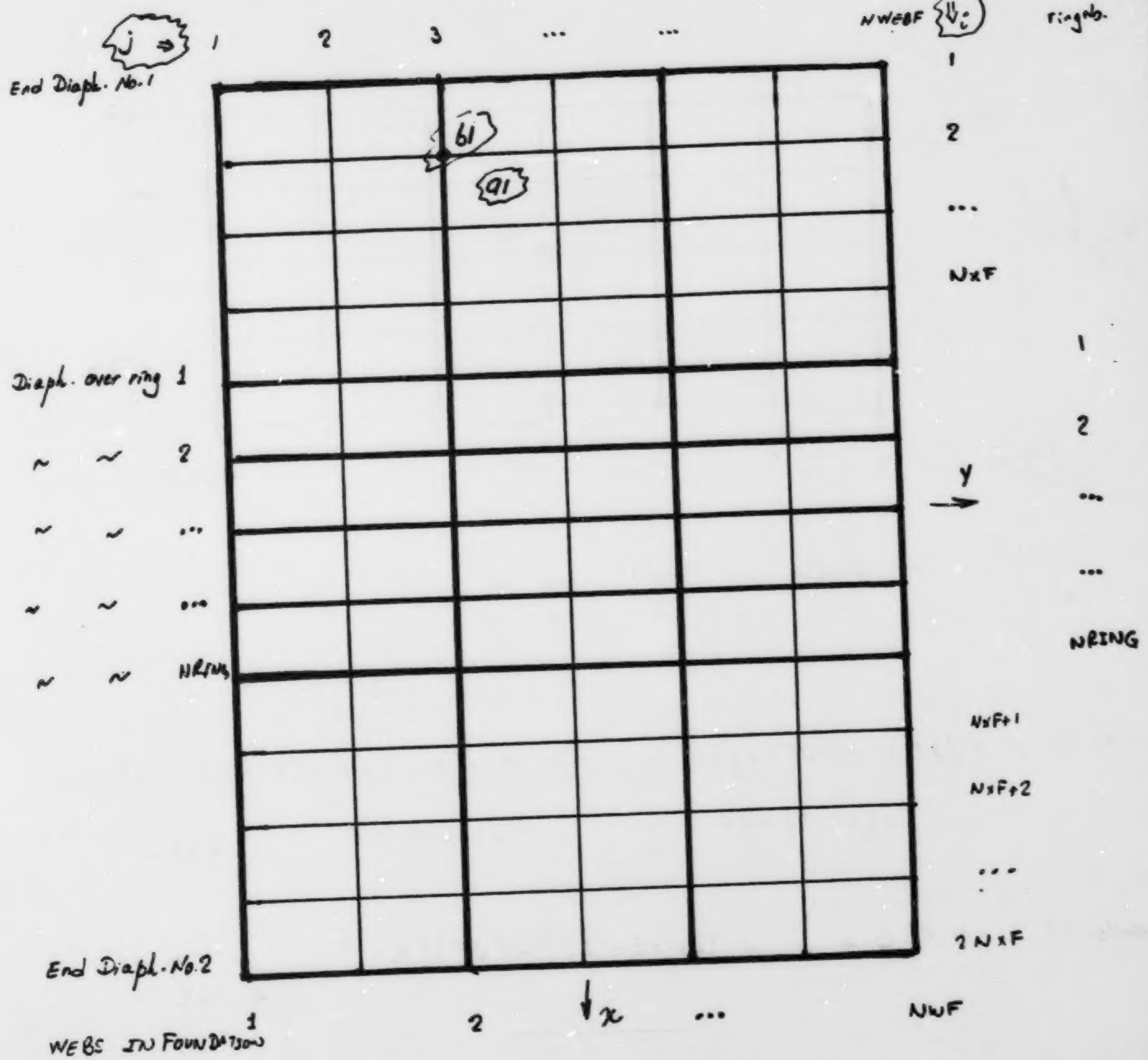
j ⇒
1
2
3
...
...
NWEBF
⇓ i
ring no.
End Diaph. No. 1
b1
a1
1
2
...
NxF
1
2
...
...
NRING
Diaph. over ring 1
~ ~ 2
~ ~ ...
~ ~ ...
~ ~ NRING
y →
NxF+1
NxF+2
...
2NxF
End Diaph. No. 2
1
2
↓ x
...
NWF
WEBS IN FOUNDATION

Node b1 = NPRG + NWEBF*(I-1) + J   i=1, 2NWF   j=1, NWEBF

Element a1 = NERG + (NWEBF-1)(I-1) + J   i=1, 2NWF   j=1, NWEBF

(see pages 2, 8-11, 19 for definitions)

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CALCULATION SHEET

END Diaphm

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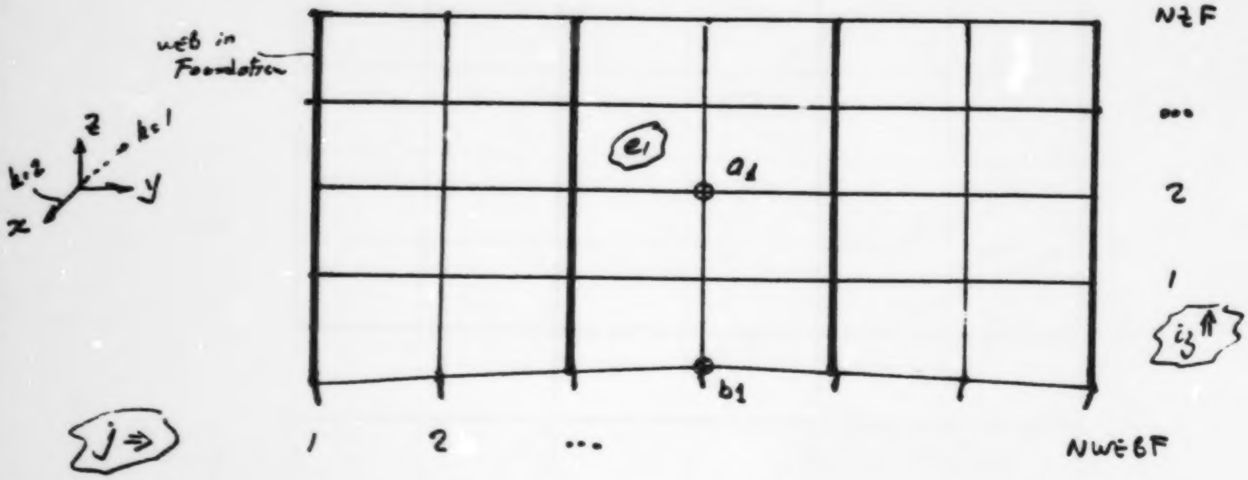
web in Foundation
z
k=1
k=2
y
x
e1
a1
b1
NZF
...
2
1
iz ⇑
j ⇒
1
2
...
NWEBF

k=1 End diaph. at most -ive x
k=2 " " " " +ive x

node a1 $= NB\phi T + NADF(iz-1) + j + [2NWF(NXF-1) + NWEBF(NRING-1)](k-1)$

$iz = 1, NZF \qquad j = 1, NWEBF \qquad k=1,2$

---

node b1 $= NPRG + j + (2NXF-1)(NWEBF)(k-1) \qquad j = 1, NWEBF \quad k=1,2$

---

element e1 $= NEB\phi T + (NWEBF-1)(iz-1) + j + NZF(NWEBF-1)(NRING+1)(k-1)$

$iz = 1, NZF \qquad j = 1, NWEBF-1 \qquad k=1,2$

(see pages 2, 8-11 & 19 for definitions)

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CALCULATION SHEET

WEBS IN FOUNDATION
BETWEEN END DIAPH. & RINGS.

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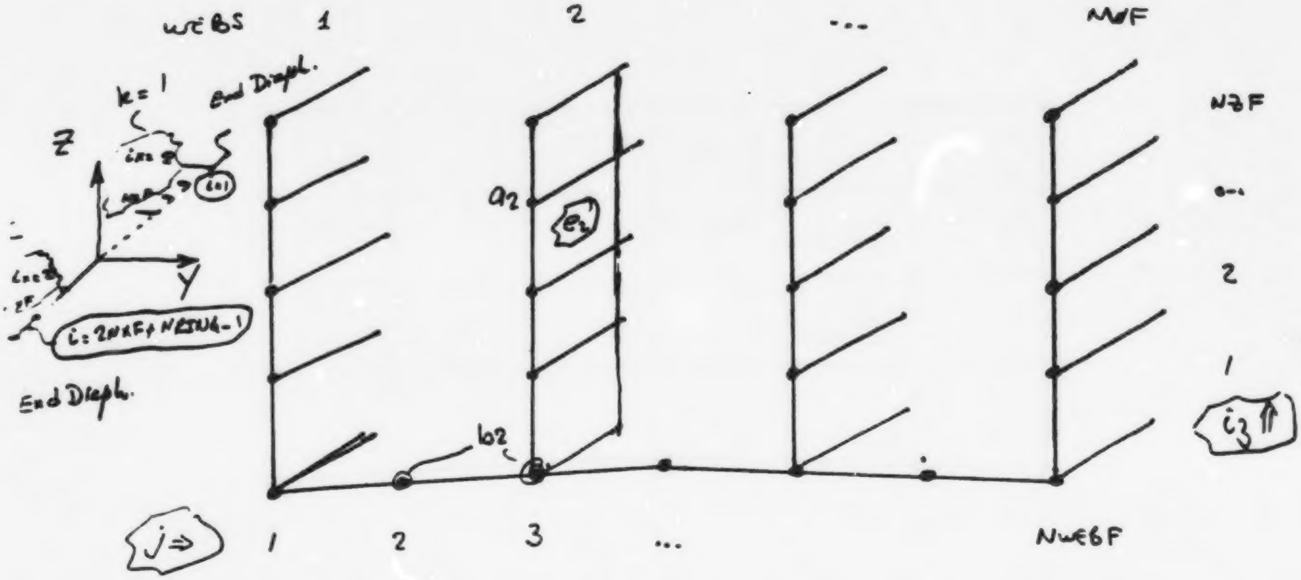
WEBS
1
2
...
NWF
k = 1
End Diaph.
Z
ix = 2
ix = 1
Y
ix = 2
2F
i = 2NXF + NRING - 1
End Diaph.
a_2
e_2
b_2
NZF
...
2
1
i_z ⇑
j ⇒
1
2
3
...
NWEBF

k = 1 for all sections between End Diaph & 1st rings (-ive x-axis)
k = 2 for all Sections between last ring & end Diaph. (+ive x-axis)

$$a_2 = NB\emptyset T + NWEBF + NADF(i_z - 1) + j + (i_x - 2)\,NWF$$
$$+ \left[NWEBF \times NRING + NWF(NXF-1) \right](k-1)$$

$i_z = 1, NZF \qquad j = 1, NWF \qquad i_x = 2, NXF \qquad k = 1, 2$

---

ce $b_2 = NPRG + j + NWEBF(i_x - 1) + NWEBF(NXF-1)(k-1)$

$j = 1, NWEBF \qquad i_x = 2, NXF \qquad k = 1, 2$

---

next $e_2 = NEB\emptyset T + (NWEBF - 1)(2 + NRING)\,NZF + i +$
$[2NXF + NRING - 1][(j-1)\,NZF + i_z - 1]$

$i = 1, 2NXF + NRING - 1 \qquad j = 1, NWF \qquad i_z = 1, NZF$

k is not used.

(see pages 2, 8-11 & 19 for definitions)

B 23

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CALCULATION SHEET

Diaph. over Rings.

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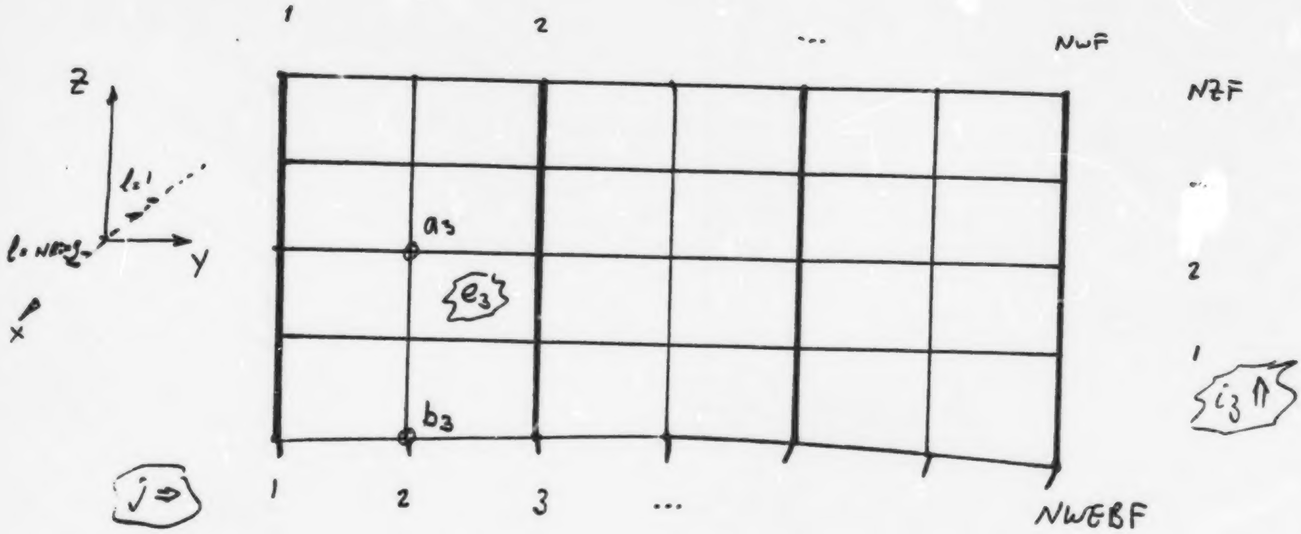

1
2
...
NWF
NZF
...
2
1
{i_z ⇑}
Z
$\ell=1$
ℓ = NRING
Y
X
a3
{e3}
b3
{j ⇒}
1
2
3
...
NWEBF

$\ell = 1,$ NRING $\qquad$ ℓ' is calculated from IWEB page 13 with $\ell = NWFS + \ell - 1$

$a3 = NB0T + NWEBF + NWF*(NXF-1) + j + NWEBF(\ell-1) + NADF(i_z-1)$

$j = 1, NWEBF \qquad \ell = 1, NRING \qquad Iz = 1, NZF$

$b3 = 3*NRING*(\ell'-1) + 3\ell \qquad \ell = 1, NRING$

ℓ' calculated from IWEB (p.13) with index = NWFS + j − 1 $\qquad j = 1,$ NWEBF

$e3 = NEB0T + (NWEBF-1)(NZF*\ell + i_z - 1) + j$

$\ell = 1, NRING \qquad j = 1, NWEBF-1 \qquad i_z = 1, NZF$

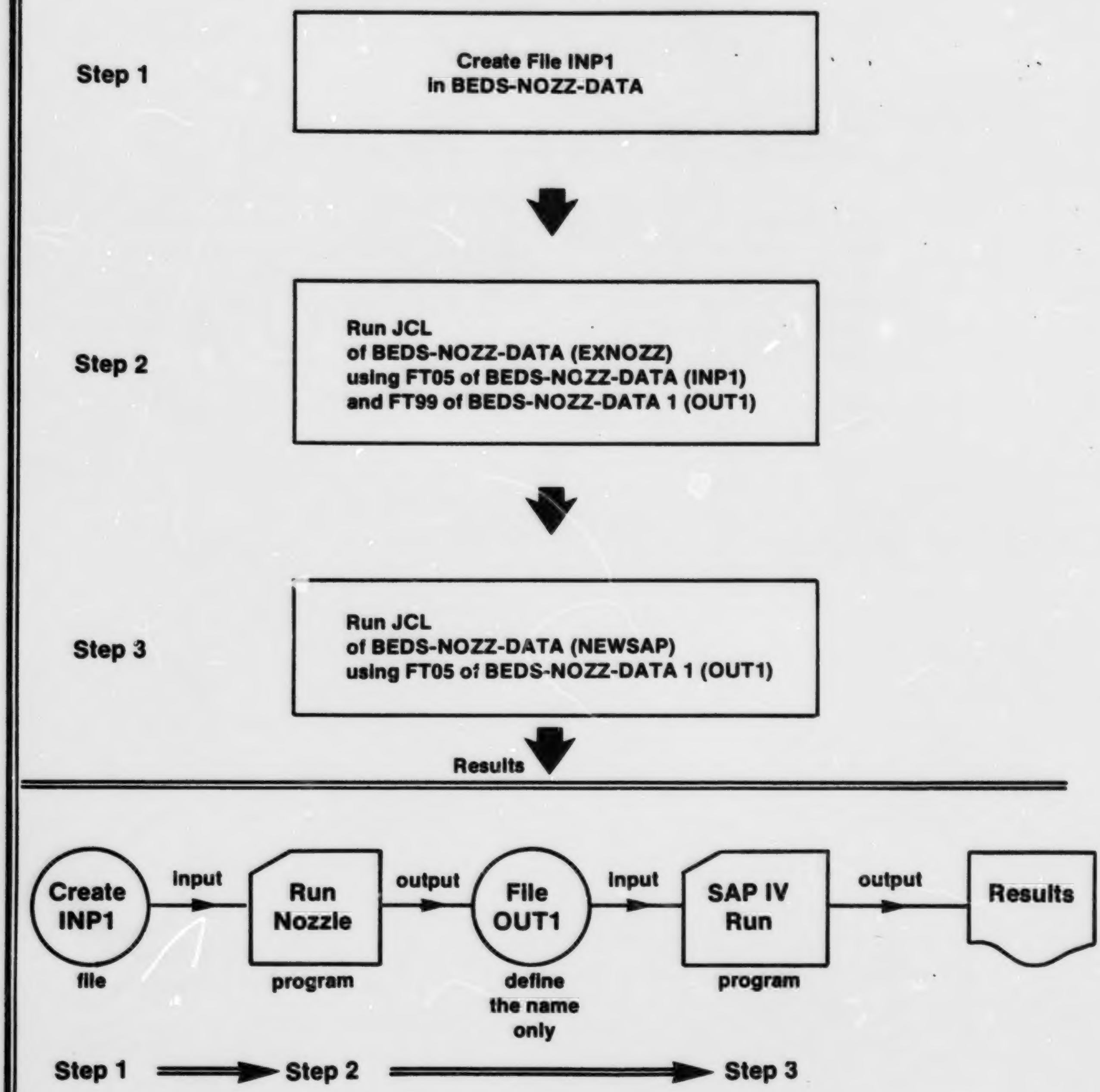
(See pages 2, 8-11 & 19 for definitions)

PROCEDURE TO CALCULATE STRESSES IN A NOZZLE

1. Create an input file using input data described on pages B27 to B30 (say name of file INP1).

2. Run program NOZZLE from BEDS.NOZZ.DATA(EXNOZZ) using file INP1 as input file and define the name of the output file (say OUT1) in BEDS,NOZZ.DATA1. Program NOZZLE will read your input data file (INP1) described on pages 25 to 29 and create a new file (OUT1) as input file for SAP IV. File INP1 is in the local file 05 and OUT1 is in the local file 99.

3. Run SAPIV from BEDS.NOZZ.DATA1(NEWSAP) using file OUT1 as your input file.



Step 1

Create File INP1
in BEDS-NOZZ-DATA

Step 2

Run JCL
of BEDS-NOZZ-DATA (EXNOZZ)
using FT05 of BEDS-NOZZ-DATA (INP1)
and FT99 of BEDS-NOZZ-DATA 1 (OUT1)

Step 3

Run JCL
of BEDS-NOZZ-DATA (NEWSAP)
using FT05 of BEDS-NOZZ-DATA 1 (OUT1)

Results
Create INP1
file
input
Run Nozzle
program
output
File OUT1
define the name only
input
SAP IV Run
program
output
Results
Step 1
Step 2
Step 3

CANADIAN MARINE DRILLING LIMITED	STRENGTH REQUIREMENTS FOR NOZZLES FOR ICE TRANSITING SHIPS	TITLE: INPUT DATA FOR PROGRAM NOZZLE FIGURE No.

INPUT DATA FOR PROGRAM "NOZZLE"

Source program is in IBM Dome Computer 'BEDS.NOZZ.FORT" (refer to page B3 for terminology used below and on pages B13 & B14).

Input Data

SET I Controls

Card 1 (24A3):Heading
Card 2 (16I5):NRING, NTHIC, NITHW, NWF, NXF, NZF
Card 3 (8F10.0):ANGW, RADIS, ARDIO, ANGF, EFØUN, HFOUN

Where:

NRING = total number of rings

NTHIC = total number of different thicknesses for webs, rings, diaphragms in foundation and webs in foundations (see Card 12)

NITHW = total number of groups for thicknesses of webs between rings (see Card 7 to 9)

NWF = total number of webs in foundation

NXF = total number of divisions of the extension of the foundation in x - direction (equal both sides)

NZF = total number of divisions of foundation in z - direction

ANGW = angle between any two webs in degrees

RADIS = radius of inner ring

ARDIØ = depth of any ring (equal to outer radius - inner radius of ring)

ANGF = angle between vertical axis (-ive z-axis) and outer foundation plate in degrees

EFØUN = distance of extension of foundation in x-direction (symmetrical)

HFØUN = height of foundation

SET II Ring Dimension

Card 4 (8F10.0):(BR(I), I=1, NRING-1)

Where:

BR(i) = distance between any two rings in x-direction from the most negative to the most positive x-axis

SET III Thickness

Card 5 (AF10.0) THIS, THØS, THFP, THFPI
Card 6 (26I3) (ITHR (I), I=1, NRING)
Card 7 (26I3) (ITHW (I, J), J=1, NITHW)
Card 8 (26I3) (ITHW (2, J), J=1, NITHW)
Card 9 (26I3) (ITHW (3, J), J=1, NITHW)
Card 10 (26I3) (ITHWF (I), I-1, NWF)
Card 11 (26I3) (ITHD (I), I=1, NRING + 2)
Card 12 (BF10.0) (THICK (I), I=1, NTHIC)

Where:

NRING, NITHW, NWF, NTHIC are defined in Set No. 1

THIS = thickness of inner shell

THØS = thickness of outer shell

THFP = thickness of foundation plate (outer shell)

THFPI = thickness of foundation plate (inner shell)

ITHR(I) = thickness type number of array THICK for each ring

ITHW(i,j)= thickness type number of array THICK for webs with i=3 from web number in the array i=1 to web number in the array i=2

NOTE: Thickness of any web is contact between any rings.

ITHD(I) = thickness type number of array THICK for all diaphragms in the foundation starting for end diaph. at most negative x-axis, followed by diaphragms over all rings, then finally the end diaphragm at the most positive x-axis. Note: Only one thickness can be used for one diaphragm.

ITHWF(I) = thicknesses type number of array THICK for all webs in the foundation. Start with the most negative y-axis to the most positive y-axis.

THICK(I) = values of different thicknesses used in the arrays ITHR, ITHW (3,J), ITHWF and ITHD.

SET IV Loadings

Card 13 (I5) NL0AD
Card 14 (I5, 2FL0.0) ITY, THETA, PRES set of cards (total number = NL0AD

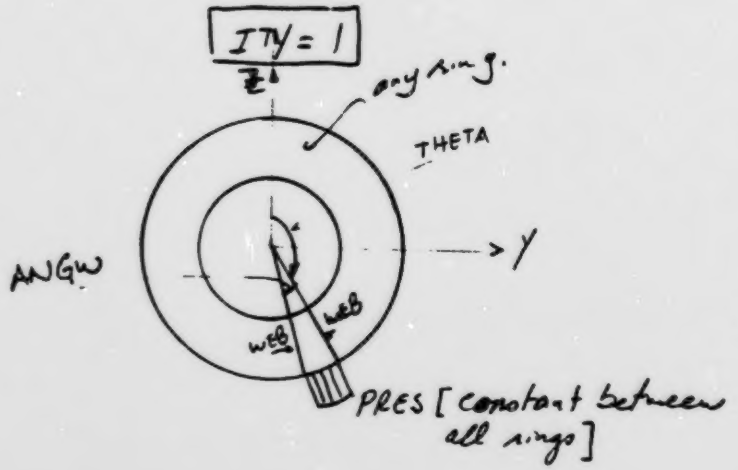
Where:

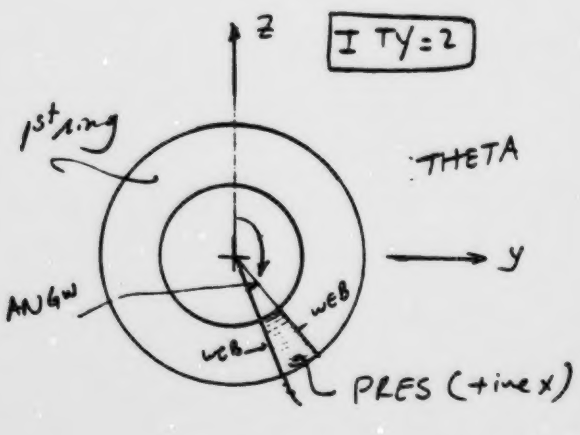
NL0AD = total number of cards used to specify pressure loadings on the rings (card 14)

ITY = type of loading (1 or 2)
ITY = 1 for radial pressure loading from 1st ring to last ring
ITY = 2 pressure loading 1st to last ring

THETA = angle in degrees where the pressure loading is applied for a distance equal to ANGW (clockwise direction)

PRES = value of pressure loading (positive as shown below)


ITY = 1
Z
any ring.
THETA
y
ANGW
WEB
WEB
PRES [constant between all rings]


Z
ITY=2
1st ring
THETA
y
ANGW
WEB
WEB
PRES (+ive x)

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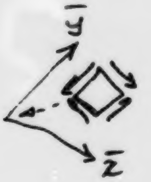
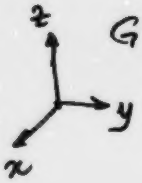
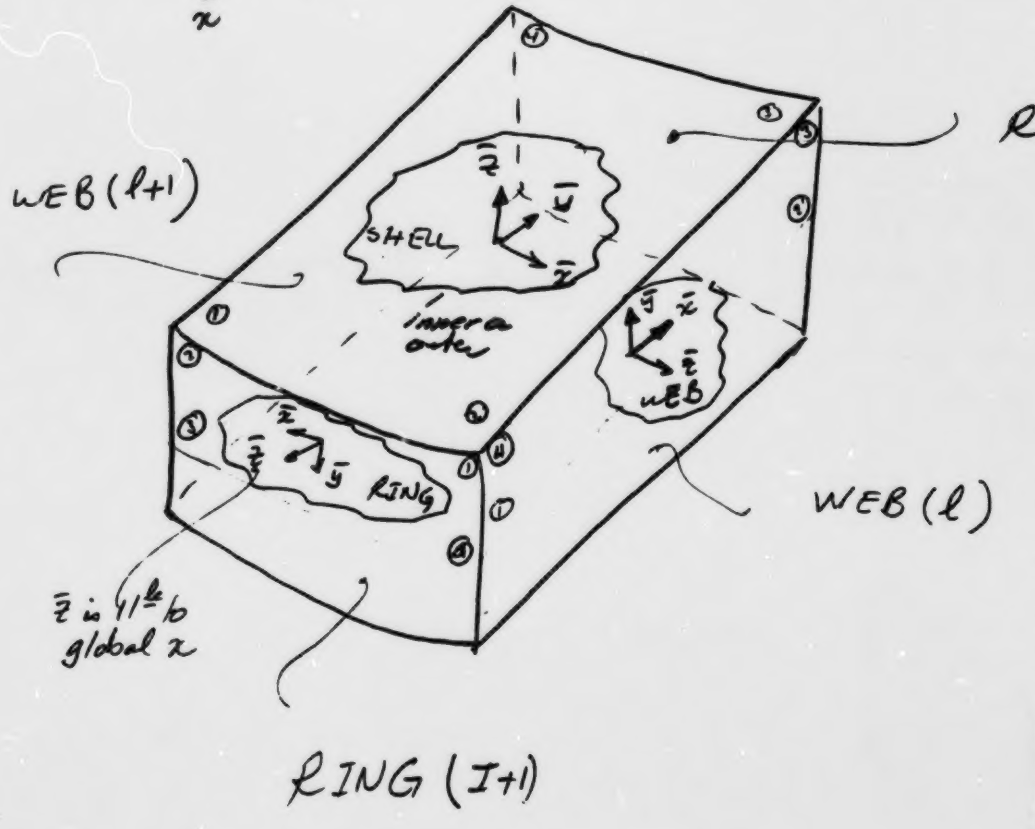
LOCAL AXES. FOR RINGS

To use the output of SAP IV, the local axes are defined as follows

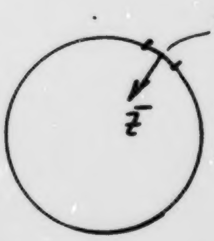


positive shear

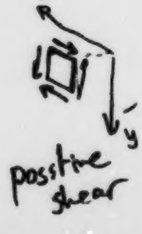



RING (I)
WEB (l+1)
SHELL
$\bar{z}$
$\bar{y}$
$\bar{x}$
inner or outer
$\bar{y}$
$\bar{x}$
$\bar{z}$
WEB
$\bar{z}$
$\bar{z}$
$\bar{y}$
RING
WEB (l)
$\bar{z}$ is $\parallel^{le}$ to global x
RING (I+1)

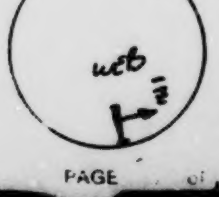
location of local $\bar{z}$



Local Axes



positive shear



LOCAL AXES
FOR FOUNDATION

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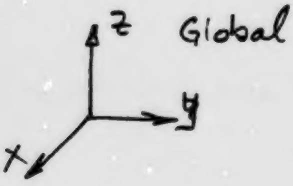
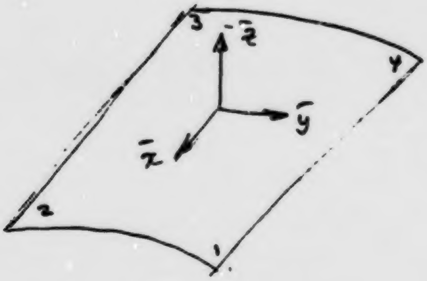
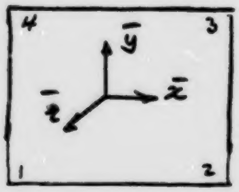
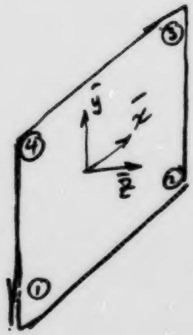



3
$\bar{z}$
4
$\bar{y}$
$\bar{x}$
2
1

Foundation Plate


4
3
$\bar{y}$
$\bar{z}$
$\bar{x}$
1
2

Diaphragm. in Foundation


③
$\bar{y}$
$\bar{x}$
④
$\bar{z}$
②
①

webs in foundation

Local axes.

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CALCULATION SHEET

Input Data for Nozzle Run

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```
                     Card  1 | HEADING
                           2 |      4     4    (12)     3      3      3
                           3 | 5.         6.          0.75         15.          1.5          2.

                           4 | 1.12       1.          1.12

                           5 | 0.036      0.036       0.027        0.036
                                                                   Total index
          ⎧  ring          6 |  1   1   1   1
          ⎪  From web      7 |  1   2  19  20  31  32  37  38  43  44  55  56      From web No.
 Thick-   ⎪  To web        8 |  1  18  19  30  31  36  37  42  43  54  55  72      To web No.
 nesses   ⎨  web           9 |  1   2   1   2   1   2   1   2   1   2   1   2
          ⎪  F.web        10 |  3   4   3
          ⎪                  |                                    Total index
          ⎪  F. Diaph     11 |  4   4   4   4   4   4
          ⎩  all thick    12 | 0.036      0.02        0.051        0.027

                             |      2 Cards of No. 14
                          13 |   (2)
                          14 |    1  85.        10.
                          14 |    1  90.        10.

      Col. No.   1234567890|1234567890|1234567890|1234567890|1234567890|1234
                          10         20         30         40         50
```

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CALCULATION SHEET

PROJECT NOZZLE STRENGTH STUDY 29 11 08

FEM - FIRST RUN

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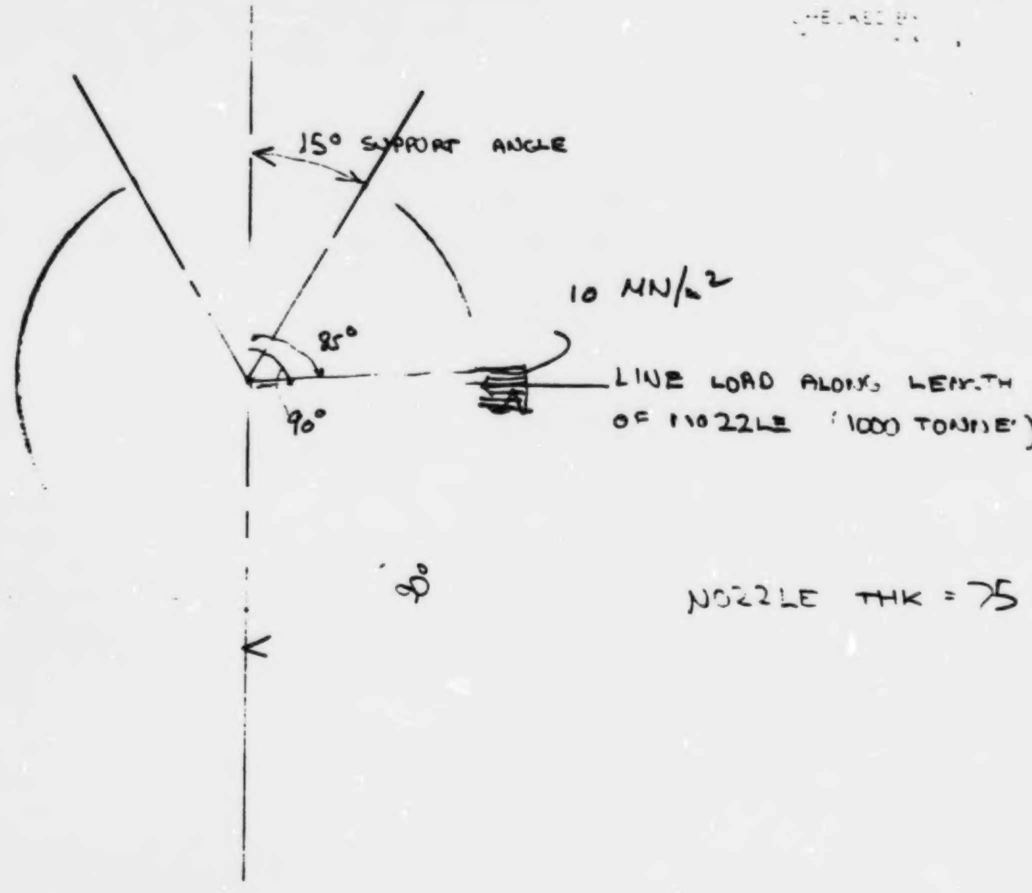
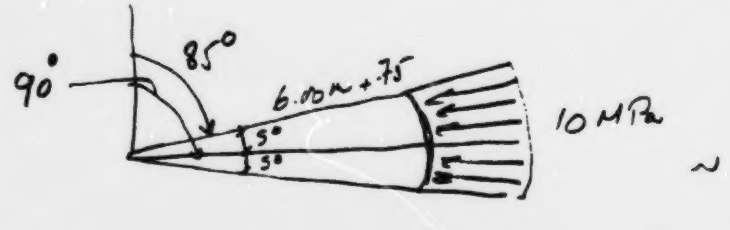

15° SUPPORT ANGLE
10 MN/m²
85°
90°
LINE LOAD ALONG LENGTH OF NOZZLE (1000 TONNE)
90°

NOZZLE THK = 75 CM.


90°
85°
6.00m + .75
5°
5°
10 MPa

total load

$P = 6.75 \times \frac{10° \times \pi}{180} \times 3.24m \times 10 = 38.17\ MN$

$R\ to\ ℄ = 6.00 + \frac{.75}{2} = 6.325m$

B34

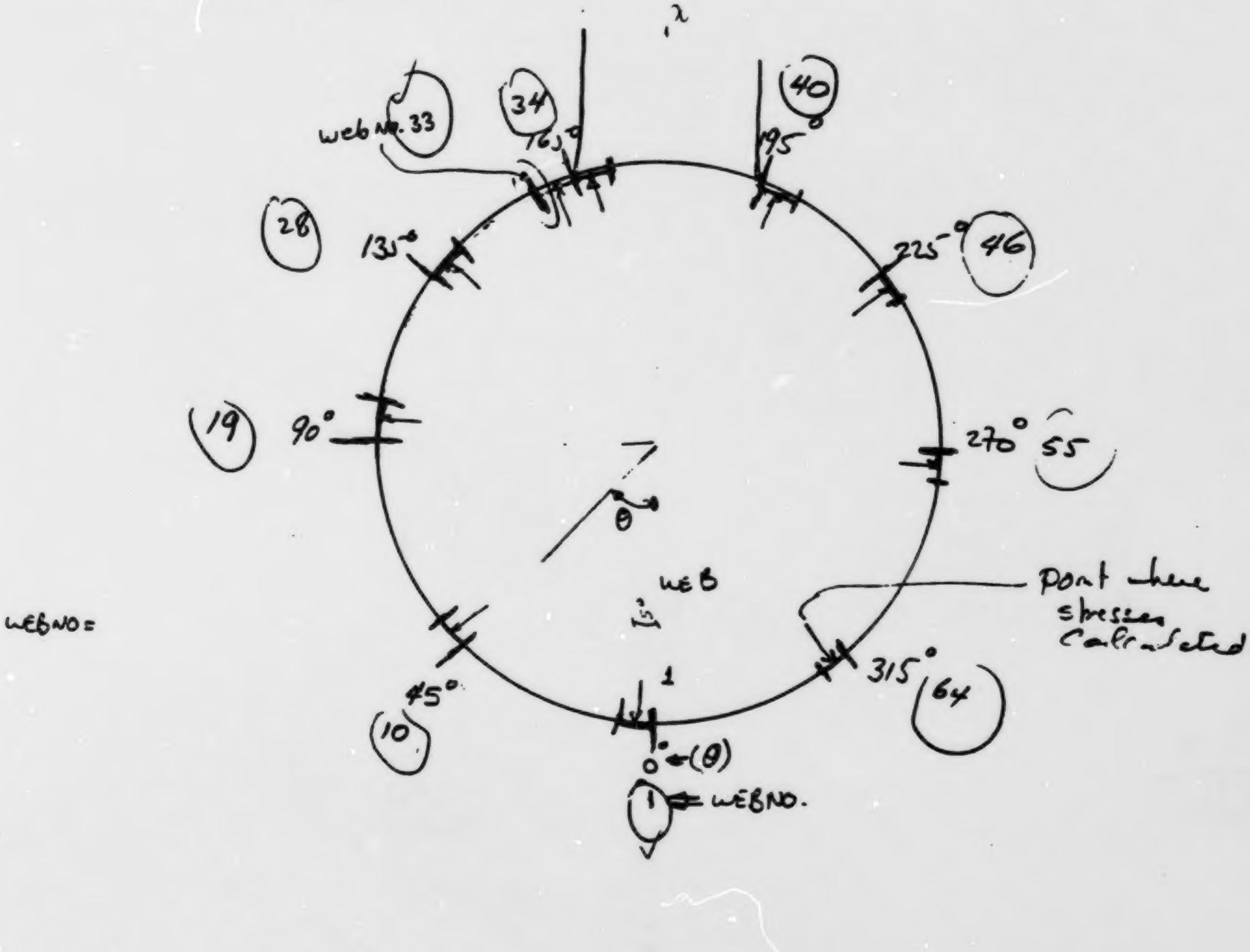
PREPARED BY
CHECKED BY

Output

Total No. of element in one web segment.

NTI (page 14) = 6x4 − 4 = 20 elements.

page 4 gives the numbering of the first 20 elements belong to WEB No. 1


λ
web No. 33
34
165°
40
195°
28
135°
225°
46
19
90°
270°
55
θ
WEB
i
WEBNO =
Point where stresses Calculated
45°
10
1
315°
64
0°←(θ)
1 ⇐ WEBNO.

$$\text{WEB No.} = \frac{\theta}{5^\circ} + 1$$

$$\text{Elements no.} = 20\{\text{WEB No} - 1\} + i \qquad i = 1,20 \text{ for one seg.}$$

CALCULATION SHEET

GENERAL for output

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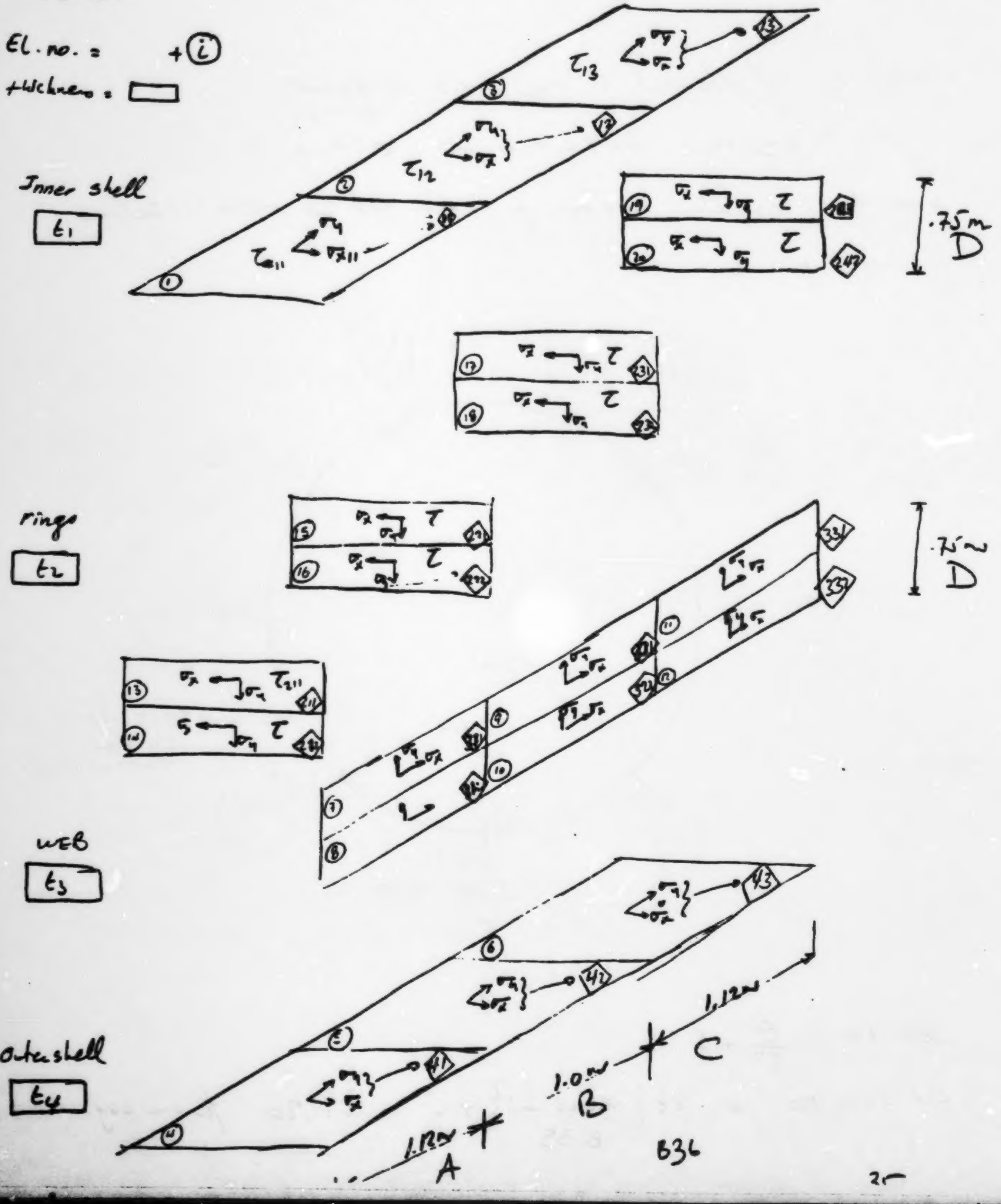
CHECKED BY

WEB NO.

El. no. = + ⓘ

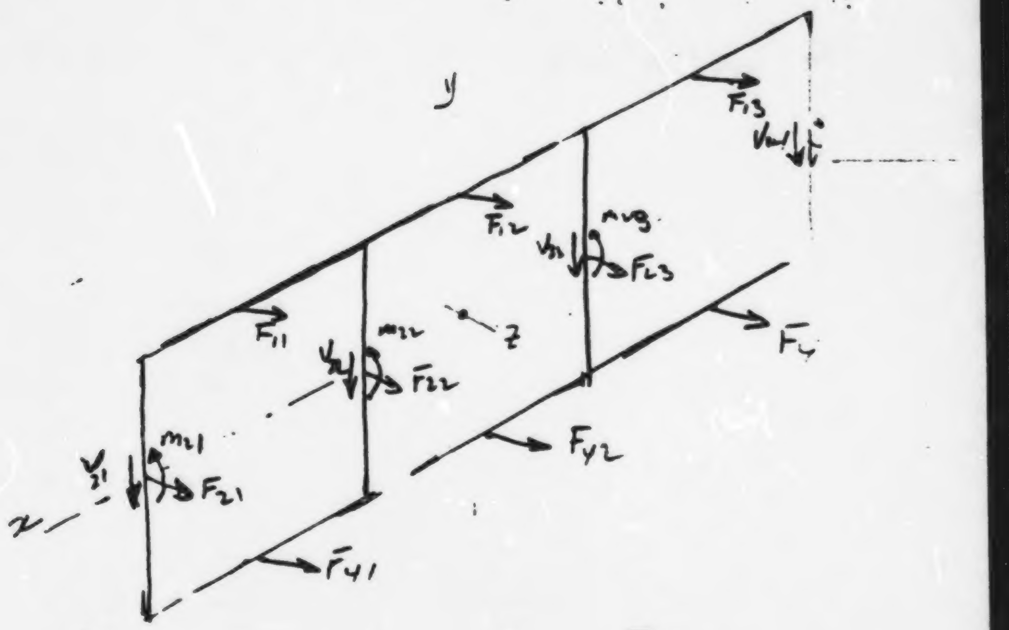
thickness = ☐


Inner shell
t_1
rings
t_2
WEB
t_3
Outer shell
t_4
τ_{13}
τ_{12}
τ_{11}
σ_y
σ_x
σ_{x11}
τ
τ_{211}
.75m
D
.75m
D
1.12m
1.0m
1.12m
A
B
C
1
2
3
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
41

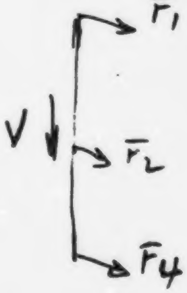
CALCULATION SHEET

GENERAL

WEB No.



y
F_{13}
V_{z3}
F_{12}
m_{z3}
V_{z2}
F_{23}
F_{11}
m_{z2}
z
F_4
V_{z2}
F_{22}
F_{y2}
m_{z1}
V_{z1}
F_{21}
x
F_{41}



Forces.

Sum of forces.

$F_{1i} = \sigma_{x1i} \times \{A \text{ or } B \text{ or } C\}\, t_1$ $\qquad F_1 = \sum F_{1i}$ $\quad i$:

$F_{2i} = (\sigma_{x2i1} + \sigma_{x2i2}) \times 0.5 D \times t_2$ $\qquad F_2 = \sum F_{2i}$ $\quad i$

$F_{4i} = \sigma_{x4i} \{A \text{ or } B \text{ or } C\} \times t_4$ $\qquad F_4 = \sum F_{4i}$ $\quad i$

$m_{2i} = +(\sigma_{zi1} - \sigma_{zi2}) \times D^2 \times t_2 / 6$ $\qquad m_2 = \sum m_{2i}$ $\quad i$

$V_{2i} = [\tau_{zi1} + \tau_{zi2}] \times 0.5 D \times t_2$ $\qquad V_n = \sum V_{2i}$ $\quad i$

$N = F_1 + F_2 + F_4$

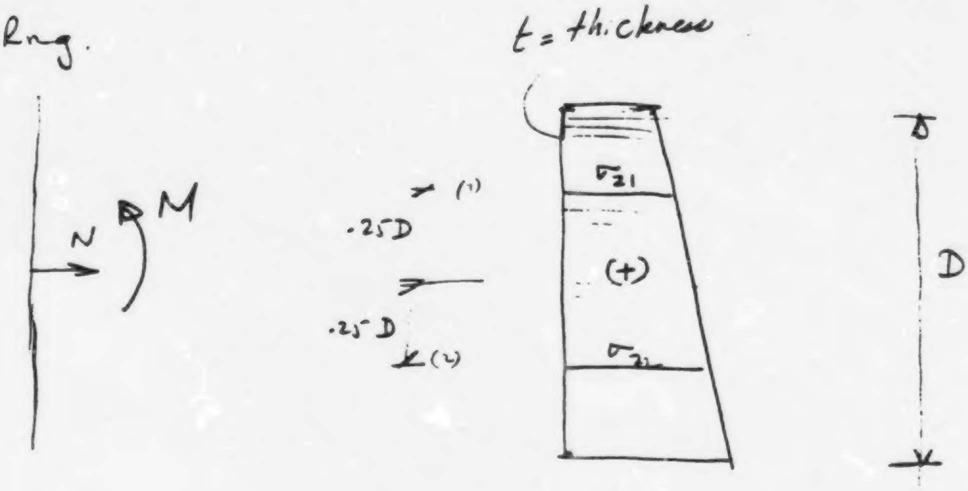
$V = V$

$M_x = (F_1 - F_4) \times 0.5 D + m_2$

See p. 38a for F_{2i} [illegible]

CALCULATION SHEET

For WEB a Rng.


t = thickness
N
M
(1)
.25D
.25D
(2)
σ_{z1}
(+)
σ_{z2}
D

$$\sigma_{z1} = \frac{N}{Dt} + \frac{M \times .25D}{\frac{tD^3}{12}} = \frac{N}{Dt} + \frac{3M}{tD^2}$$

$$\sigma_{z2} = \qquad = \frac{N}{Dt} - \frac{3N}{tD^2}$$

$$\frac{2N}{Dt} = \sigma_{z1} + \sigma_{z2} \qquad \frac{6N}{tD^2} = \sigma_{z1} - \sigma_{z2}$$

$$N = (\sigma_{z1} + \sigma_{z2}) \frac{tD}{2} \quad \longleftarrow$$

$$M = (\sigma_{z1} - \sigma_{z2}) \frac{tD^2}{6} \quad \longleftarrow$$

DOME PETROLEUM LIMITED

CALCULATION SHEET

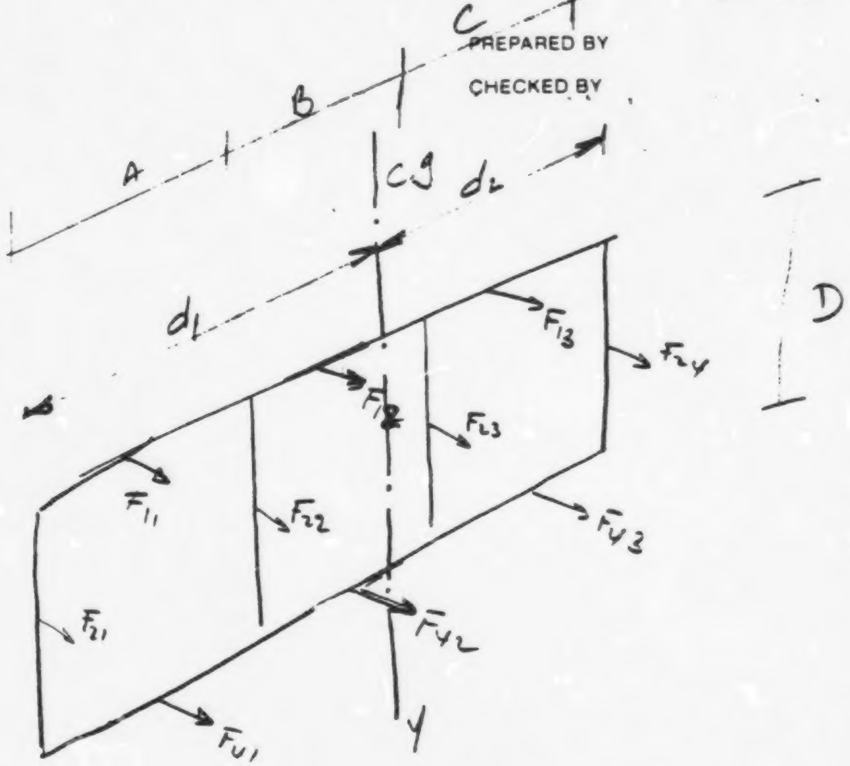
COST CENTRE OR AFE No

DATE YEAR MONTH DAY

TITLE PROJECT

PREPARED BY

CHECKED BY


A
B
C
cg
d_2
d_1
D
F_{13}
F_{24}
F_{12}
F_{23}
F_{11}
F_{22}
F_{43}
F_{21}
F_{42}
F_{41}
y

$$
\begin{aligned}
M_y = {} & (F_{11}+F_{41})(d_1 - .5A) + (F_{12}+F_{42})(d_1 - A - .5B) \\
& - (F_{13}+F_{43})(d_2 - .5C) + F_{21}\times d_1 + F_{22}\times(d_1 - A) \\
& - F_{23}(d_2 - C) - F_{24}\times d_2
\end{aligned}
$$

B39

COST CENTRE
CR AFE NO

DOME PETROLEUM LIMITED
CALCULATION SHEET

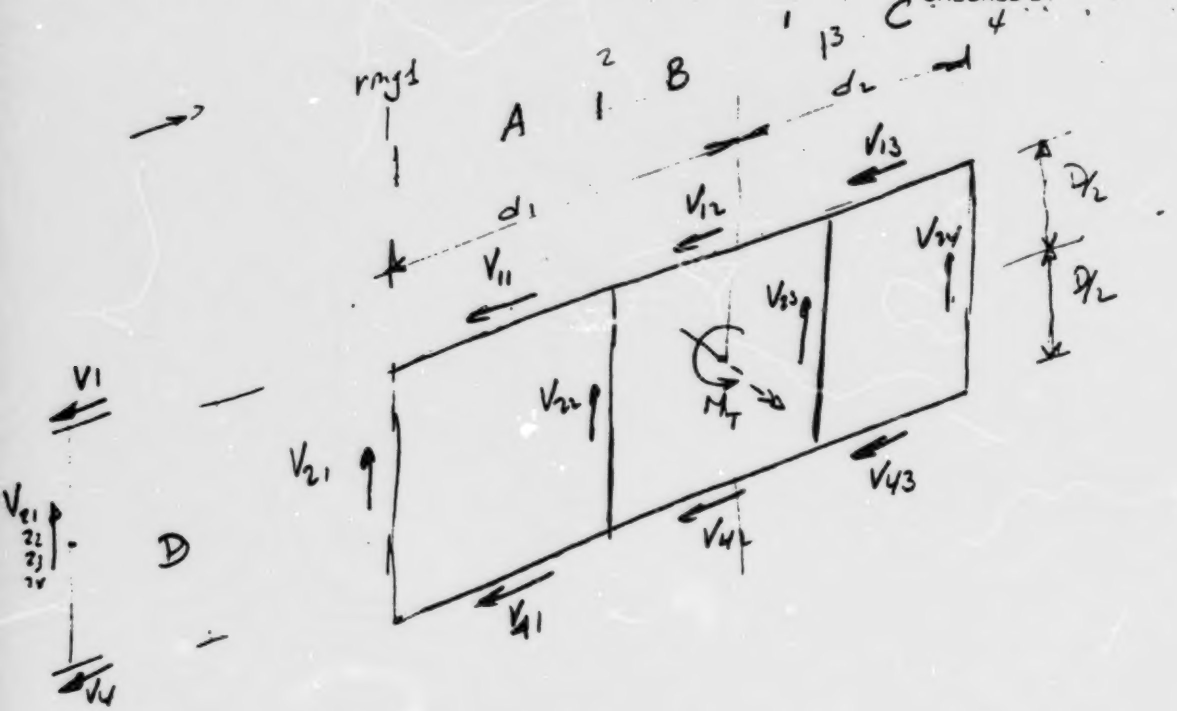
594
79-08

DATE YEAR MONTH DAY

TITLE PROJECT

PREPARED BY

CHECKED BY



rng 1
A
2
B
1
3
C
4
d_2
d_1
V_{11}
V_{12}
V_{13}
V_{24}
V_{23}
V_{22}
V_{21}
M_T
V_{43}
V_{42}
V_{41}
D/2
D/2
V1
V_{21}
22
23
24
D
V_4

$$V_{1i} = \tau_{1i} \times \{A \text{ or } B \text{ or } C\}\, t_1 \qquad i = 1,2,3 \qquad V_1 = \sum_{i=1}^{3} V_{1i}$$

$$V_{4i} = \tau_{4i} \times \{A \text{ or } B \text{ or } C\} \times t_4 \qquad i = 1,2,3 \qquad V_4 = \sum_{i=1}^{3} V_{4i}$$

$$V_{2i} = \{\tau_{2i1} + \tau_{2i2}\} \frac{D}{2} \times t_2 \qquad i = 1,2,3,4$$

$$M_T = (V_1 - V_4)\frac{D}{2} - V_{21} d_1 - V_{22}(d_1 - A) + V_{23}(d_2 - C) + V_{24} \times d_2$$

$$V = V_1 + V_4$$

CALCULATION SHEET

WEB No. 1

El. no. = 0 + ⓘ

thickness = ☐

Inner shell

.036

rings

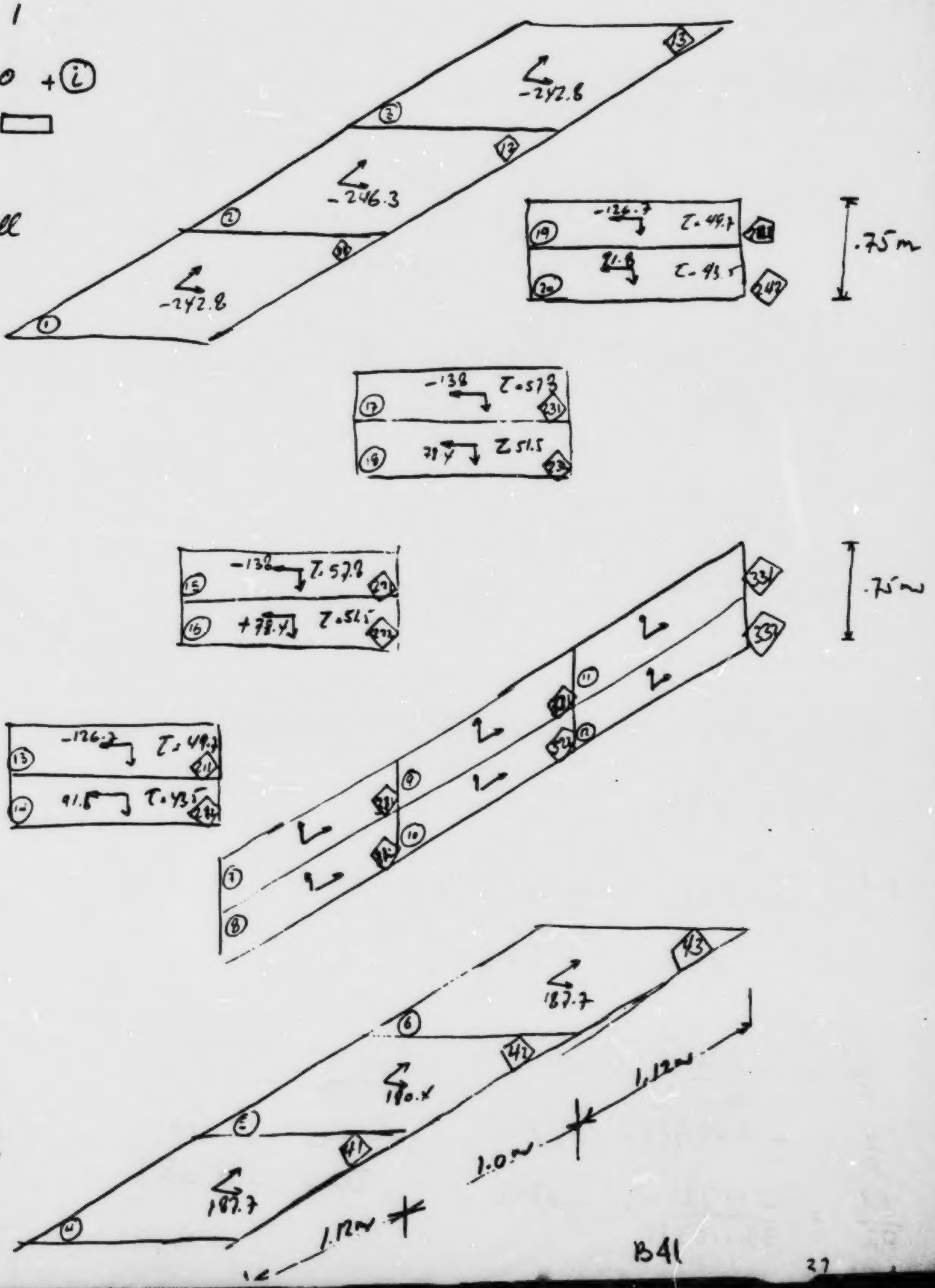
.036

web

.036

Outershell

.036



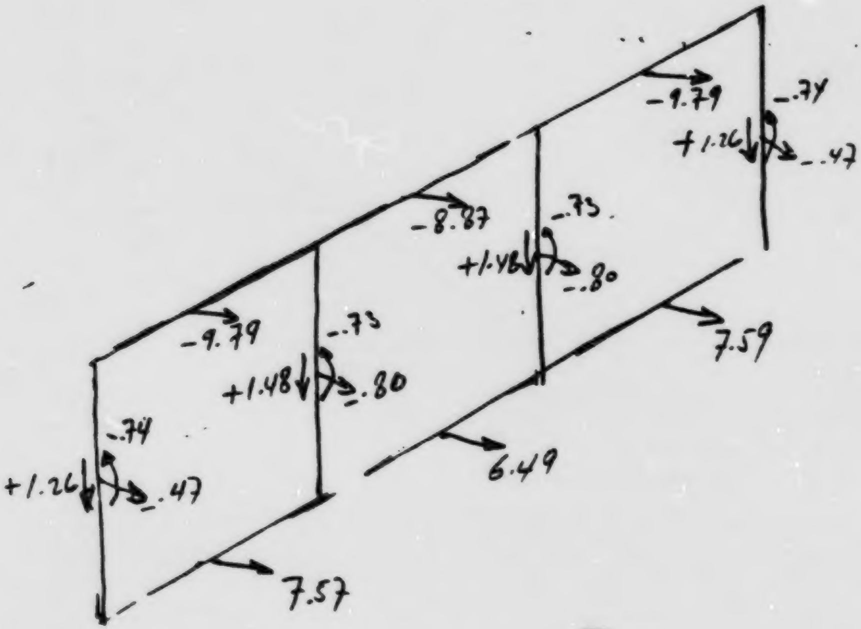
③
②
①
13
12
-242.8
-246.3
-242.8
⑲
⑳
-126.7
τ = 49.7
91.8
τ = 43.5
.75 m
⑰
⑱
-138
τ = 57.8
78.4
τ 51.5
231
⑮
⑯
-138
τ = 57.8
+78.4
τ = 51.5
⑬
⑭
-126.2
τ = 49.7
91.5
τ = 43.5
.75 m
⑦
⑧
⑨
⑩
⑪
⑫
33
⑥
⑤
④
43
42
41
187.7
180.4
187.7
1.12 m
1.0 m
1.12 m

B41

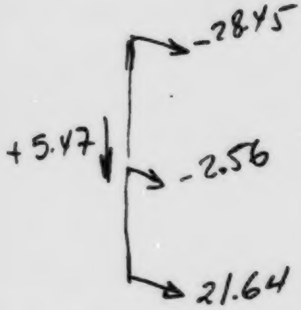
CALCULATION SHEET

WEB No. 1

$P = 38.2$ MN
$R = 6.375$ m


-9.79
-.74
+1.26
-.47
-8.87
-.73
+1.48
-.80
-9.79
-.73
+1.48
-.80
7.59
-.74
+1.26
-.47
6.49
7.57

Forces.


-28.45
+5.47
-2.56
21.64

Sum of forces.

$N = -28.45 - 2.56 + 21.64 = -9.36$

$V = -5.47$

$M = (-28.45 - 21.64) \times \frac{.75}{2} + \{-.74 - .73 - .73 - .74\}$

$= -18.78 - 2.94 = -21.72$

$\frac{N}{P} = -\frac{9.36}{38.2} = 0.245$ Done -0.231

$\frac{V}{P} = -5.47/38.2 = -.144$ Done $+.149$

$\frac{M}{PR} = \frac{-21.72}{38.2 \times 6.375} = -.0892$ Done -0.081

CALCULATION SHEET

RUN # 1

WEB No. 10

El. no. = 180 + ⓘ

thickness = ☐

Inner shell

.036

rings

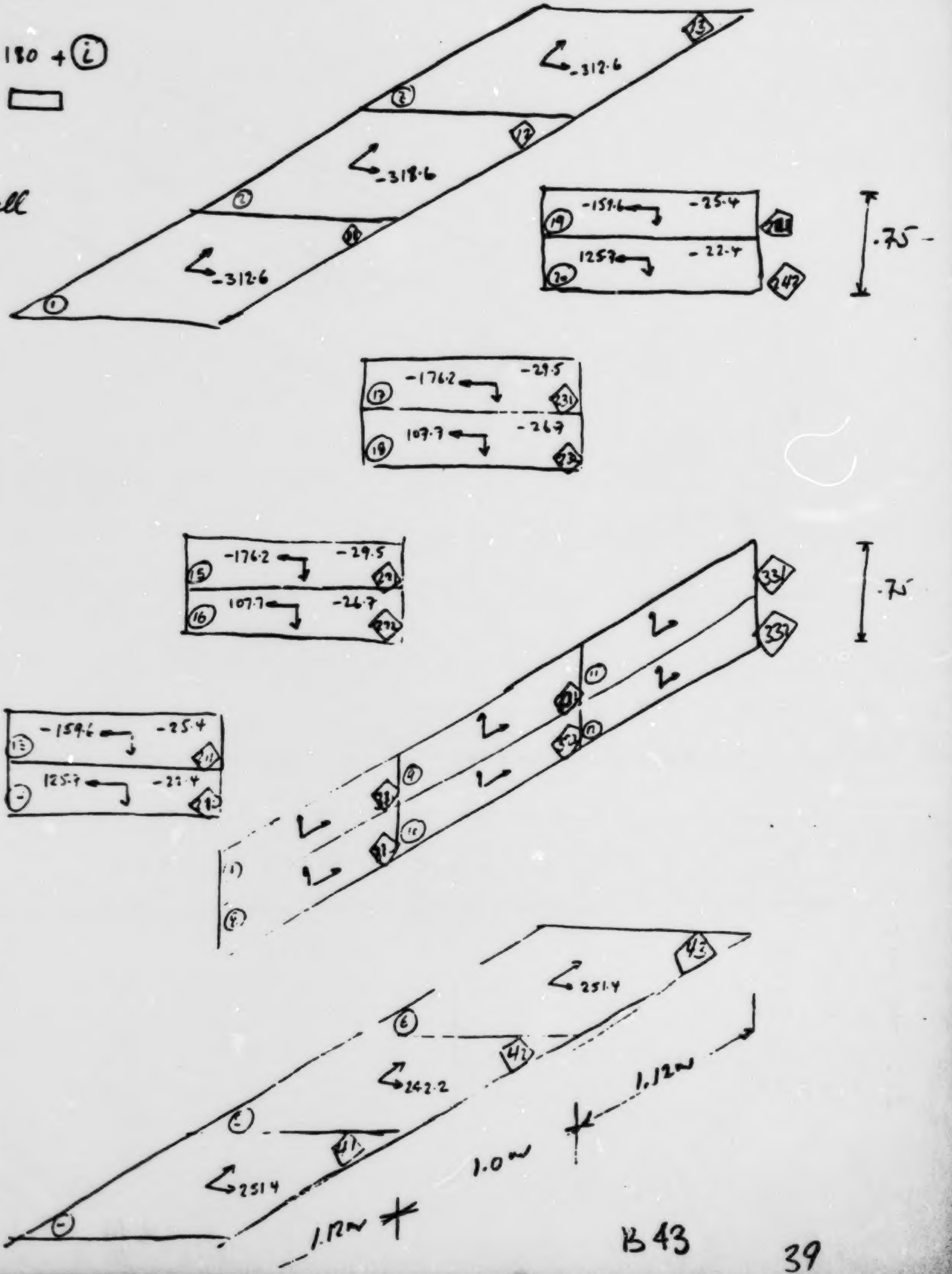
.036

web

.036

Outer shell

.036



①
②
③
⑰
⑱
⑲
-312.6
-318.6
-312.6
⑲ -159.6 -25.4
⑳ 125.7 -22.4
.75
⑰ -176.2 -29.5 ㉛
⑱ 107.7 -26.7 ㉜
⑮ -176.2 -29.5 ㉙
⑯ 107.7 -26.7 ㉚
⑬ -159.6 -25.4
⑭ 125.7 -22.4
㉝
㉞
.75
⑪
⑫
⑨
⑩
⑦
⑧
⑥
⑤
④
㊸
㊷
㊶
251.4
242.2
251.4
1.12m
1.0m
1.12m

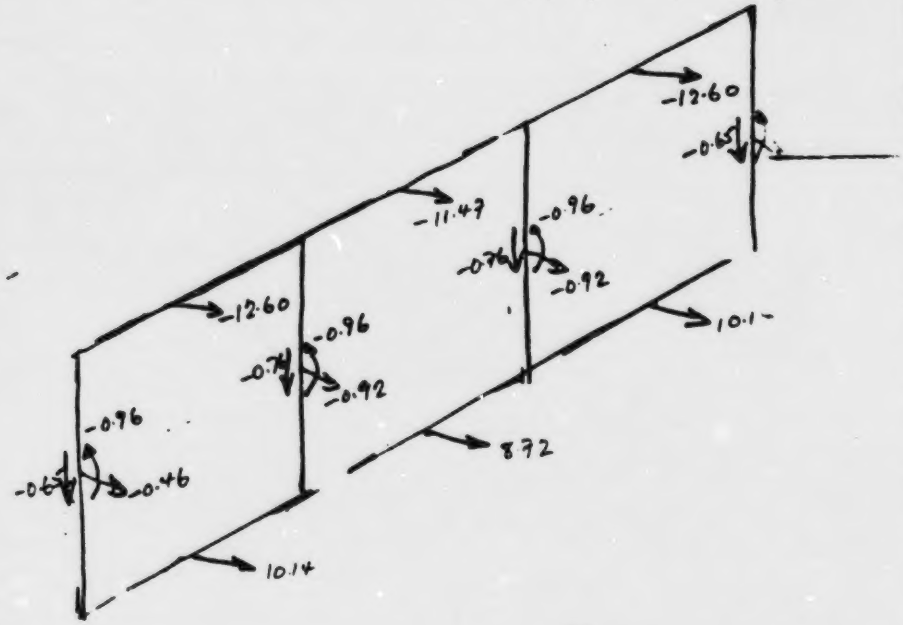
B43

CALCULATION SHEET

WEB No. 10

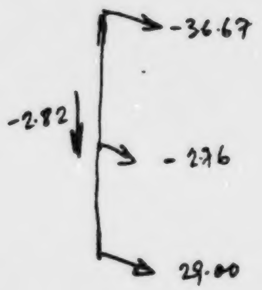
$P = 30.17$

$\gamma = 6.375$



-12.60
-0.65
-11.47
-0.96
-0.76
-0.92
-12.60
-0.96
-0.74
-0.92
10.1
-0.96
-0.65
-0.46
8.72
10.14

Forces.



-36.67
-2.82
-2.76
29.00

Sum of forces.

$N = -36.67 + (-2.76) + 29.00 = -10.43$

$M_z = (-0.96) \times 4 \quad = -3.84$

$V = -2.82$

$M = [-36.67 - (29.00)] \times 0.5 \times 0.75 + (-3.84) = -28.47$

	[illegible]
$\frac{N}{P} = -0.273$	-0.269
$\frac{V}{P} = -0.074$	-0.058
$\frac{M}{PE} = -0.117$	-0.19

CALCULATION SHEET

RUN# 1

WEB NO. 19

El. no. = 360 + ⓘ

thickness = ☐

Inner shell

0.036

rings

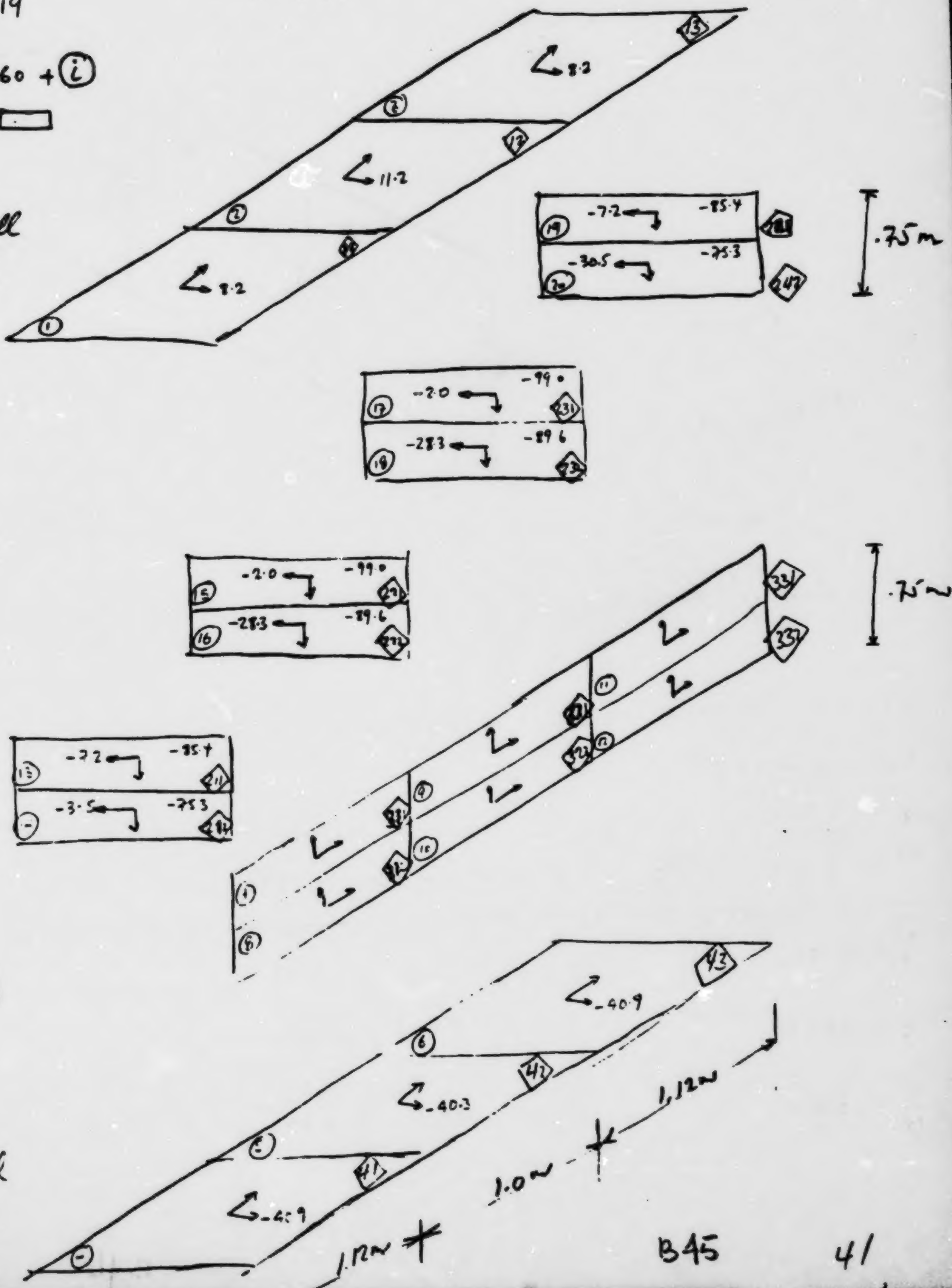
0.036

web

0.036

Outer shell

0.036

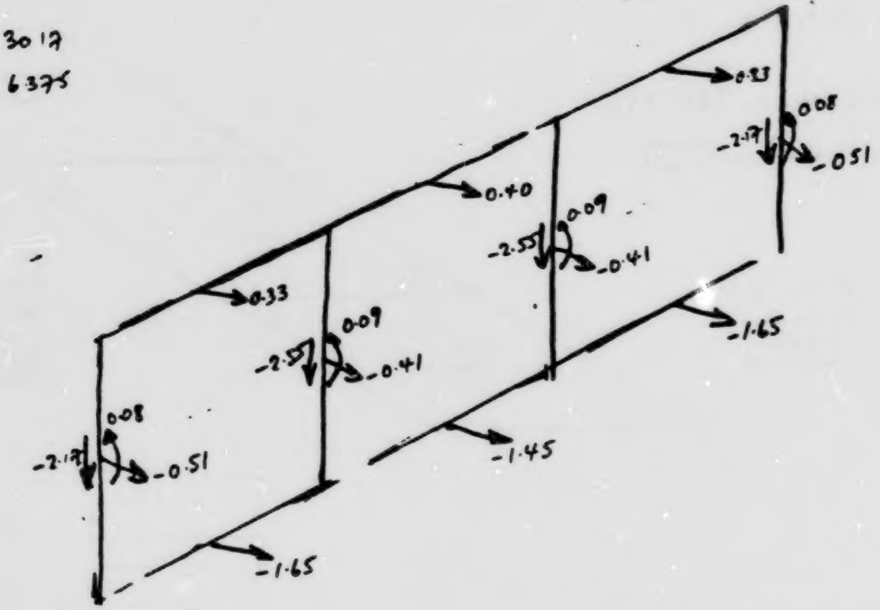


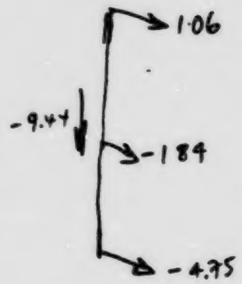
8.2
11.2
8.2
①
②
②
13
17
18
-7.2
-85.4
19
21
-30.5
-75.3
20
24
.75m
-2.0
-99.0
17
31
-28.3
-89.6
18
32
-2.0
-99.0
15
27
-28.3
-89.6
16
28
.75m
33
35
11
12
21
22
9
10
31
32
7
8
-7.2
-85.4
13
11
-3.5
-75.3
14
-40.9
-40.3
-40.9
⑥
43
42
41
1,12m
1.0m
1.12m

CALCULATION SHEET

WEB No. 19

P = 3017
r = 6375


0.33
0.08
-2.17
-0.51
0.40
0.09
-2.55
-0.41
-1.65
0.33
0.09
-2.55
-0.41
0.08
-2.17
-0.51
-1.45
-1.65


1.06
-9.44
-1.84
-4.75

Forces.

Sum of forces.

$N = 1.06 + (-1.84) + (-4.75) = -5.53$

$M_2 = (0.08 + 0.09) \times 2 = 0.34$

$V = -9.44$

$M = [1.06 - (-4.75)] \times 0.5 \times 0.75 - 0.34 = 2.52$

SAP	DONE
$\frac{N}{P} = -0.145$	-0.149
$\frac{V}{P} = -0.247$	-0.231
$\frac{M}{PR} = 0.010$	0.00

CALCULATION SHEET

PREPARED BY

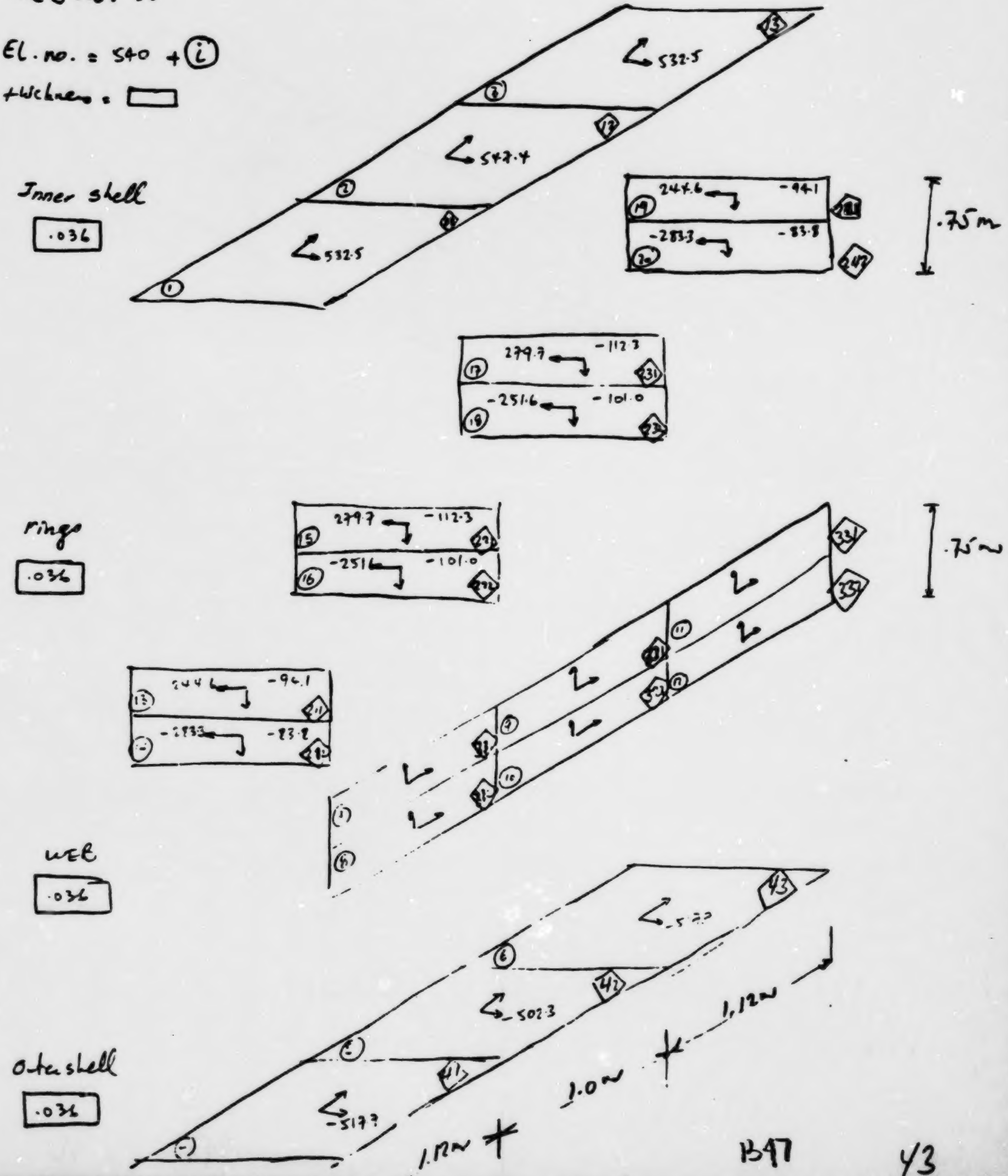
CHECKED BY

RUN# 1

WEB NO. 28

El. no. = 540 + ⓘ

thickness = ▭

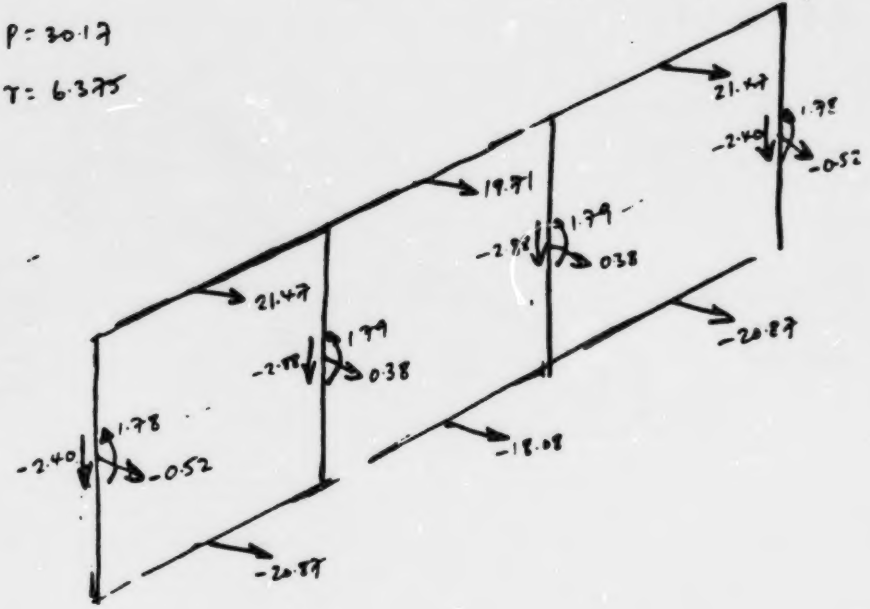

Inner shell
.036
532.5
547.4
532.5
1
2
3
13
17
18
244.6
-94.1
-283.3
-83.8
19
20
.75m
279.7
-112.3
-251.6
-101.0
17
18
rings
.036
279.7
-112.3
-251.6
-101.0
15
16
244.6
-94.1
-283.3
-83.2
13
14
33
35
.75m
7
8
9
10
11
12
web
.036
-5??
-502.3
-517.7
43
42
41
6
5
Outer shell
.036
1.12m
1.0m
1.12m

CALCULATION SHEET

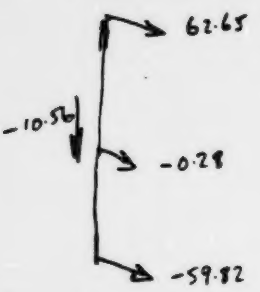
WEB No. 28

P = 30.17

T = 6.375


21.47
1.78
-2.40
-0.52
19.71
1.79
-2.88
0.38
21.47
1.79
-2.88
0.38
-20.87
1.78
-2.40
-0.52
-18.08
-20.87

Forces.


62.65
-10.56
-0.28
-59.82

Sum of forces.

$N = 62.65 + (-0.28) + (-59.82) = 2.55$

$M_z = (1.78 + 1.79) \times 2 = 7.14$

$V = -10.56$

$M = [62.65 - (-59.82)] \times 0.5 \times .75 + 7.14 = 53.07$

SAP IV	DONE
$\frac{N}{P} = 0.067$	0.058
$\frac{V}{P} = -0.277$	-0.269
$\frac{M}{PL} = 0.218$	0.207

CALCULATION SHEET

RUN # 1

WEB No. 33

El. no. = 640 + (i)

thickness = ▭

Inner shell

.036

rings

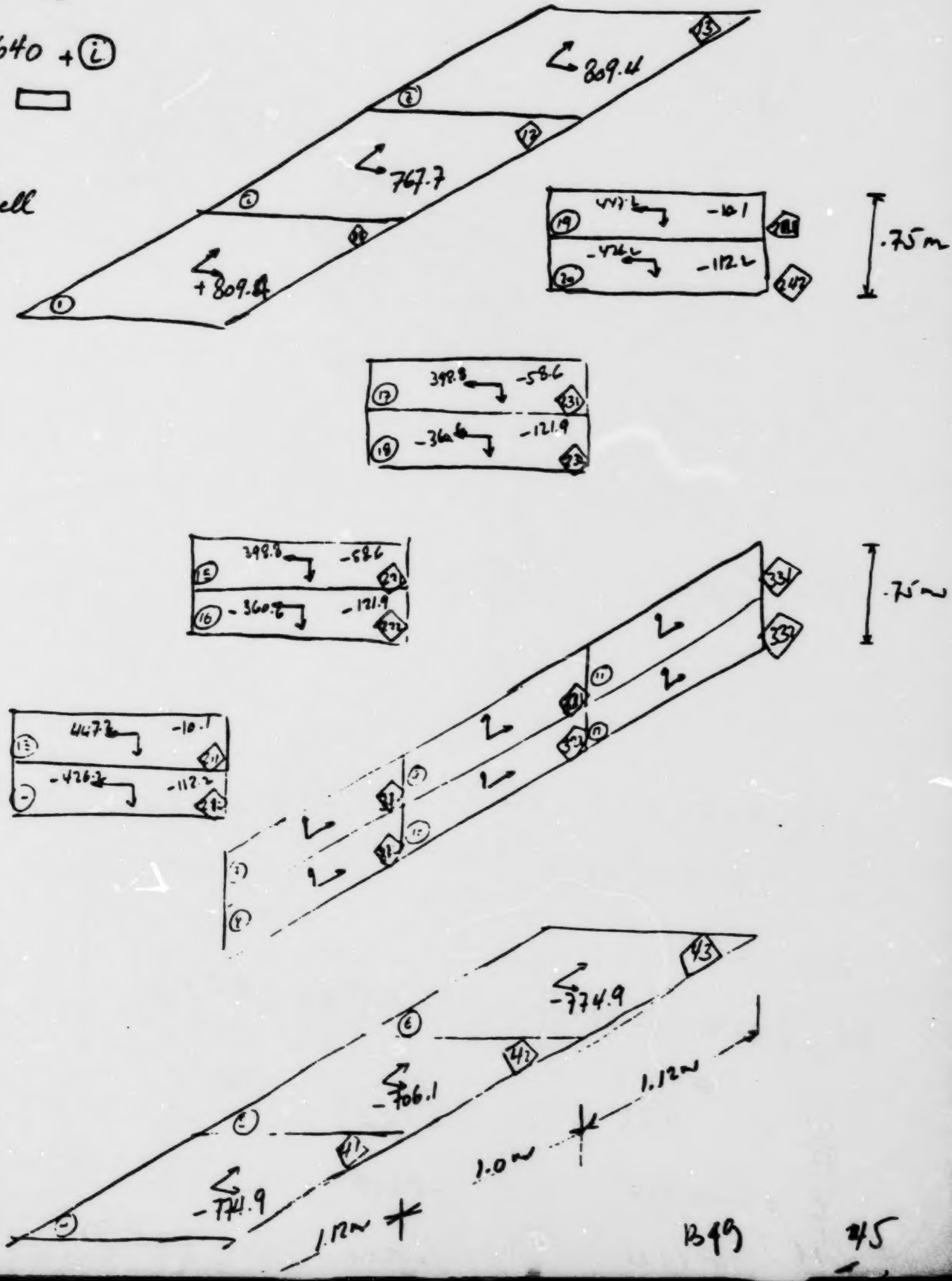
.036

web

.036

Outer shell

.036



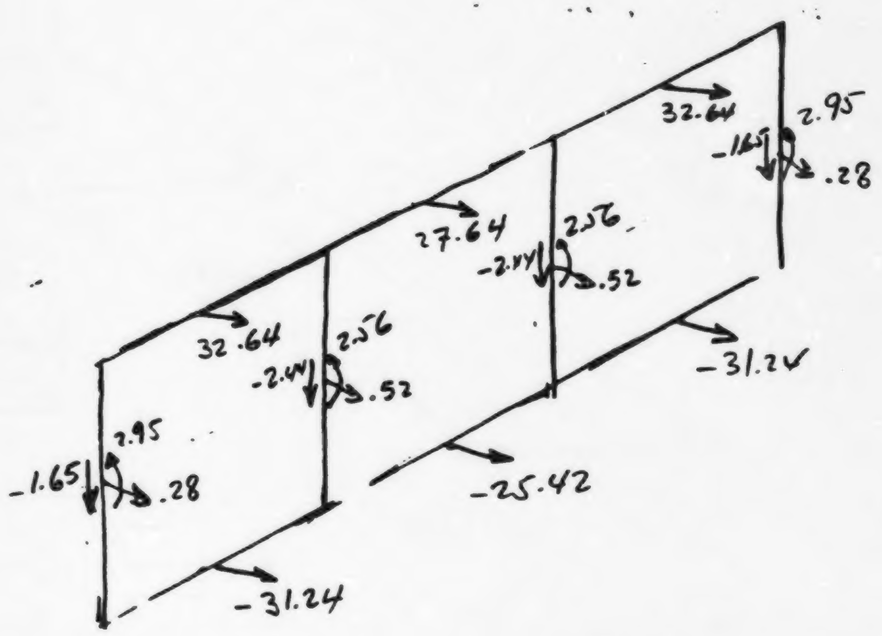
33
809.4
2
17
767.7
2
18
+809.4
1
447.2
-10.1
19
18
-426.2
-112.2
20
24
.75 m
348.8
-58.6
17
23
-360.2
-121.9
18
23
348.8
-58.6
15
29
-360.2
-121.9
16
29
447.2
-10.1
13
21
-426.2
-112.2
21
34
35
.75 m
11
31
32
33
32
43
-774.9
6
42
-706.1
1.12 m
4
41
1.0 m
-774.9
1.12 m

B49

CALCULATION SHEET

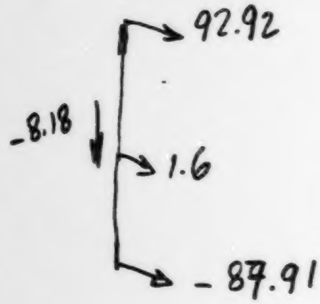
WEB No. 33

P = 38.17
R = 6.375



32.64
2.95
-1.65
.28
27.64
2.56
-2.44
.52
32.64
2.56
-2.44
.52
-31.24
2.95
-1.65
.28
-25.42
-31.24

Forces.



92.92
-8.18
1.6
-87.91

Sum of forces.

$N = 92.92 + 1.6 - 87.91 = 6.61$

$m_2 = (2.95 + 2.56) \times 2 = 11.02$

$V = -8.18$

$M = \left[92.92 - (-87.91)\right]^{67.81} \times 0.5 \times .75 \pm 11.02 = \cancel{8}78.83$

	SAP II ($\theta = -167.5°$)	Done ($\theta = -165.$)
$\frac{N}{P}$ =	0.173	.184
$\frac{V}{P}$ =	-0.214	-0.204
M	0.224	.321

B50 46

CALCULATION SHEET

WEB NO. 40

RUN# 1

El. no. = 780 + ⓘ

thickness = ☐

Inner shell

.036

rings

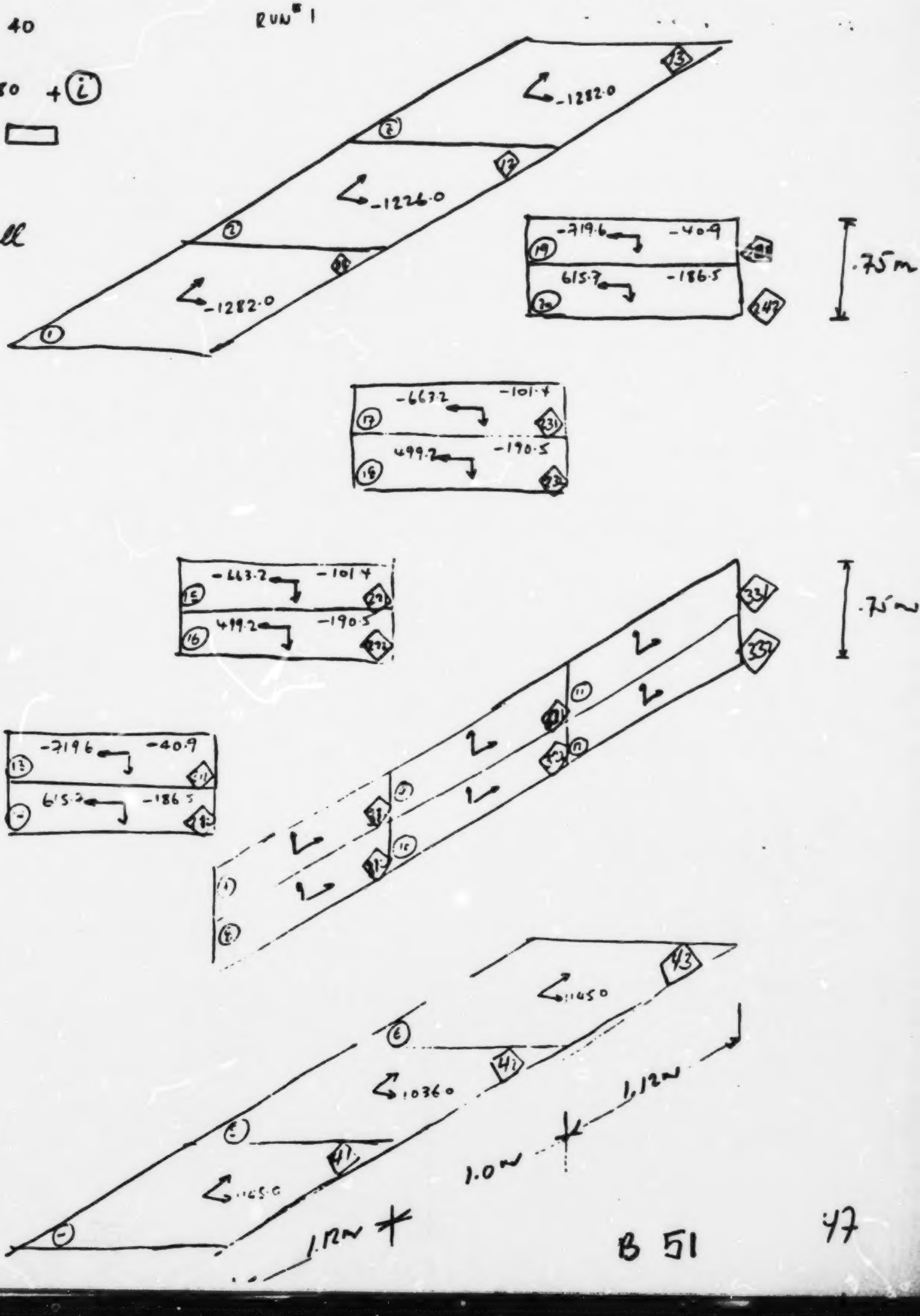
.036

web

.036

Outer shell

.036



-1282.0
-1226.0
-1282.0
①
②
②
-719.6
-40.9
615.7
-186.5
.75m
-663.2
-101.4
499.2
-190.5
-663.2
-101.4
499.2
-190.5
.75m
-719.6
-40.9
615.7
-186.5
1.12m
1.0m
1.12m
1145.0
1036.0
1165.0

B 51

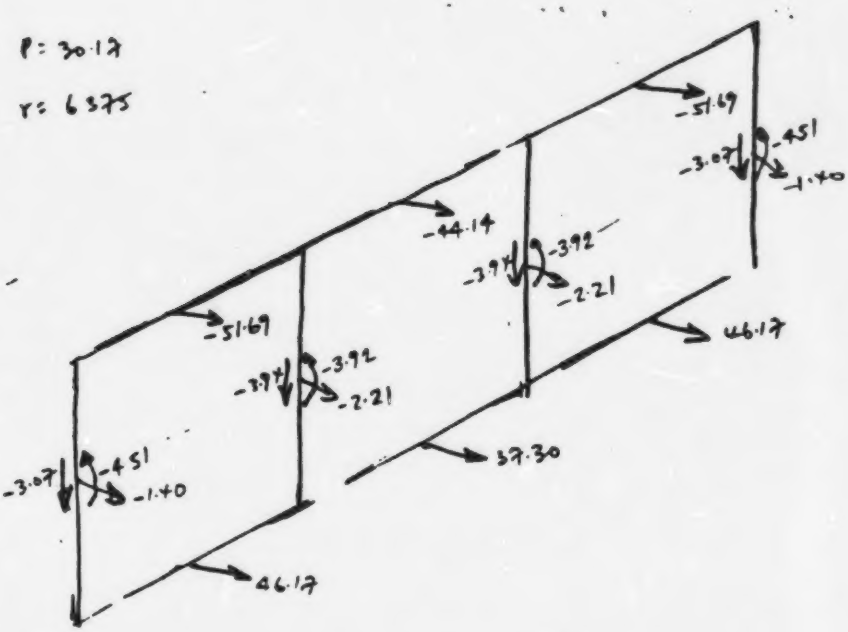
47

CALCULATION SHEET

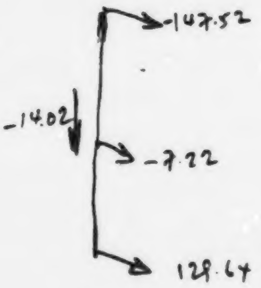
WEB No. 40

$P = 30.17$

$r = 6.375$


-51.69
-4.51
-3.07
-1.40
-44.14
-3.92
-3.94
-2.21
46.17
-51.69
-3.92
-3.94
-2.21
37.30
-4.51
-3.07
-1.40
46.17

Forces.


-147.52
-14.02
-7.22
128.64

Sum of forces.

$N = -147.52 - 7.22 + 128.64 = -25.1$

$M_2 = (-4.51 - 3.92) \times 2 = -16.86$

$V = -14.02$

M = [- 42.52 - 28.64 [illegible] × 75 + (-16.86) = -120.80

SAP IV	DONE
$\frac{N}{F} = -0.658$	-0.704
$\frac{V}{F} = -0.367$	-0.343
$\frac{M}{FS} = -0.496$	-0.555

B52 48

CALCULATION SHEET

---------=B No. 46

RUN# 1

·no. = 900 + ⓘ

lines = ▭

inner shell

336

ings

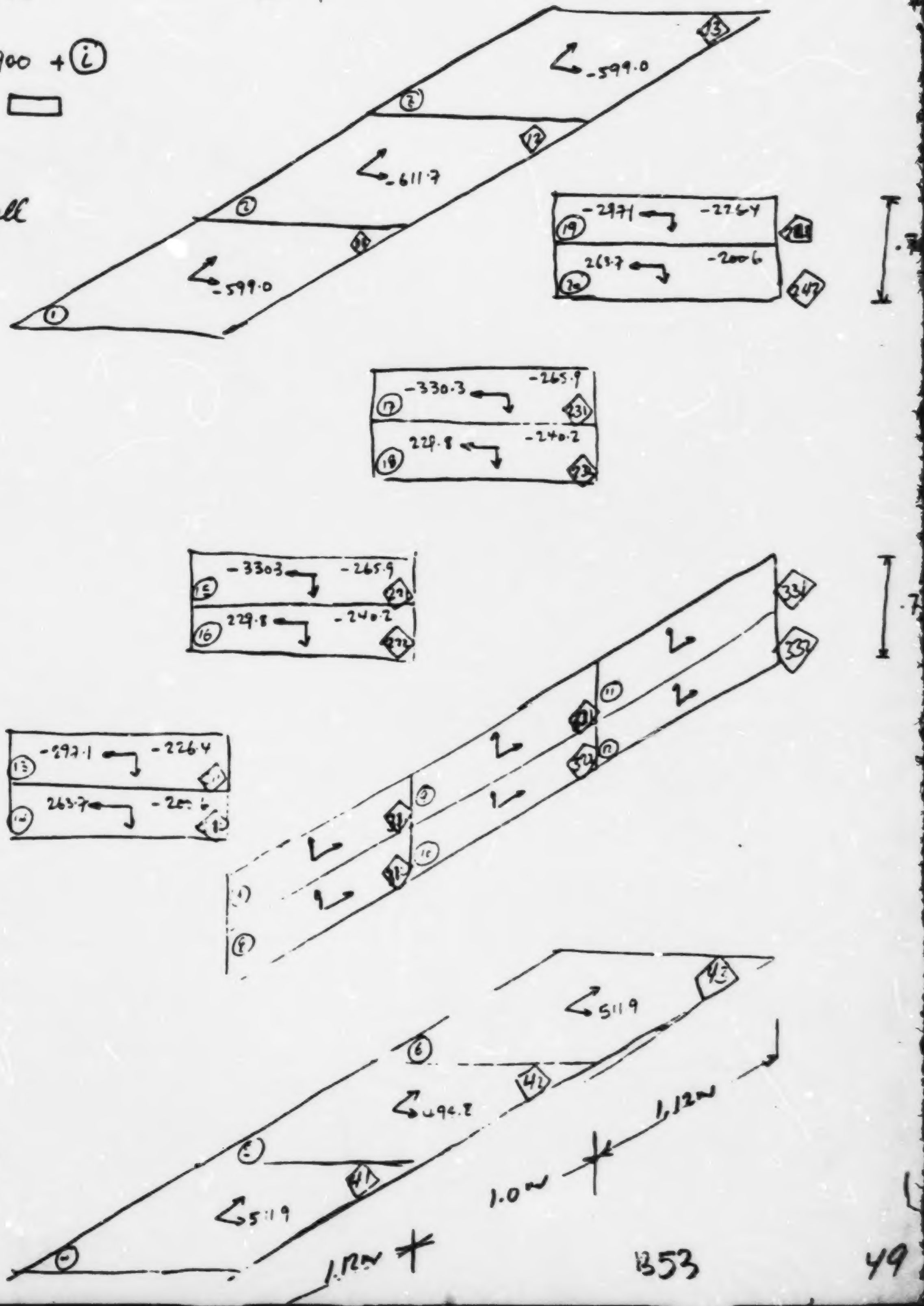
36

el

36

shell

36



13
-599.0
2
12
-611.7
2
11
-599.0
1
19
-297.1
-226.4
20
263.7
-200.6
24
17
-330.3
-265.9
231
18
229.8
-240.2
232
15
-330.3
-265.9
16
229.8
-240.2
13
-297.1
-226.4
14
263.7
-200.6
.7
33
35
11
31
32
9
31
10
7
8
.7
43
-511.9
6
42
-494.8
5
41
-511.9
1
1.12W
1.0W
1.12W

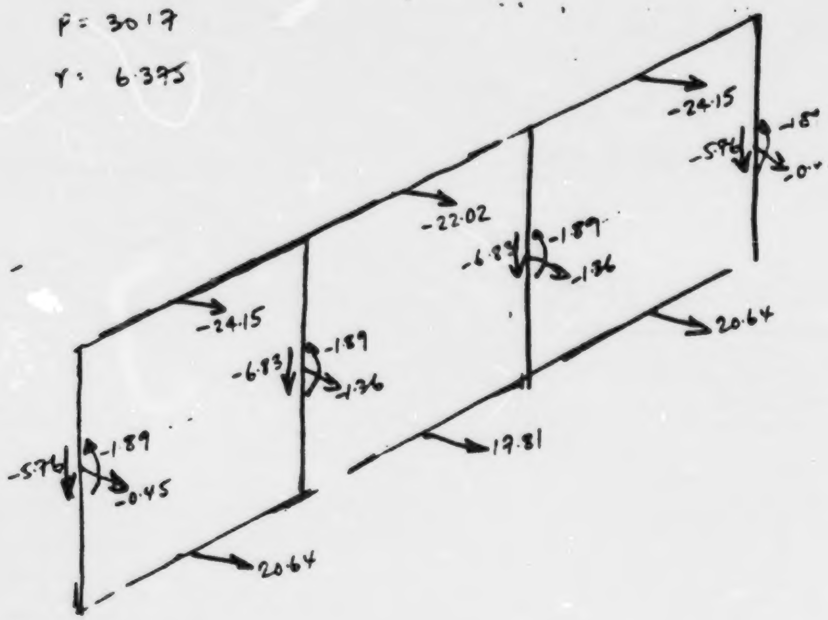
CALCULATION SHEET

CHECKED BY

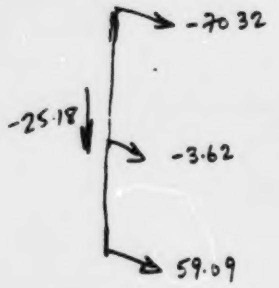
WEB No. 46

$P = 30.17$

$r = 6.375$


-24.15
-22.02
-24.15
-1.89
-6.83
-1.36
-1.89
-5.76
-0.45
-1.89
-6.83
-1.36
-1.8
-5.96
-0.4
20.64
17.81
20.64

Forces.


-70.32
-25.18
-3.62
59.09

Sum of forces.

$N = -70.32 - 3.62 + 59.09 = -14.85$

$m_2 = (-1.89) \times 4 = -7.56$

$V = -25.18$

$M = [-70.32 - (59.09)] \times 0.5 \times$ [illegible] $+ (-7.56) = -56.09$

SET IV	DOME
$\frac{N}{P} = -0.389$	-0.435
$\frac{V}{P} = -0.660$	-0.649
$\frac{M}{Pa} = -0.231$	-0.287

CALCULATION SHEET

PREPARED BY

CHECKED BY

WEB NO. 55

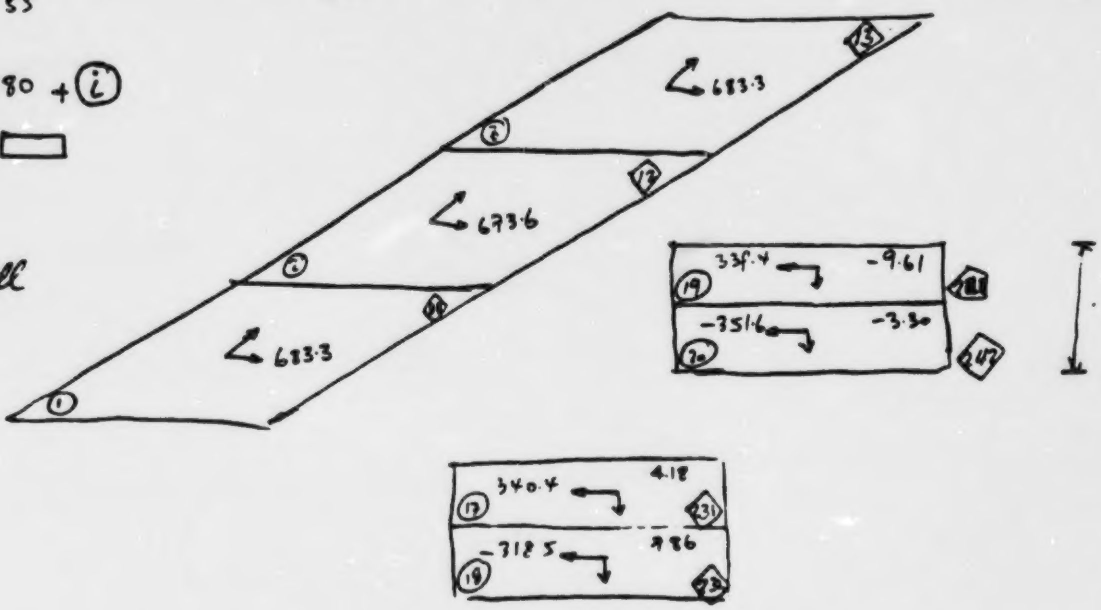
RUN# 1

El. no. = 1080 + (i)

thickness = ▭

Inner shell

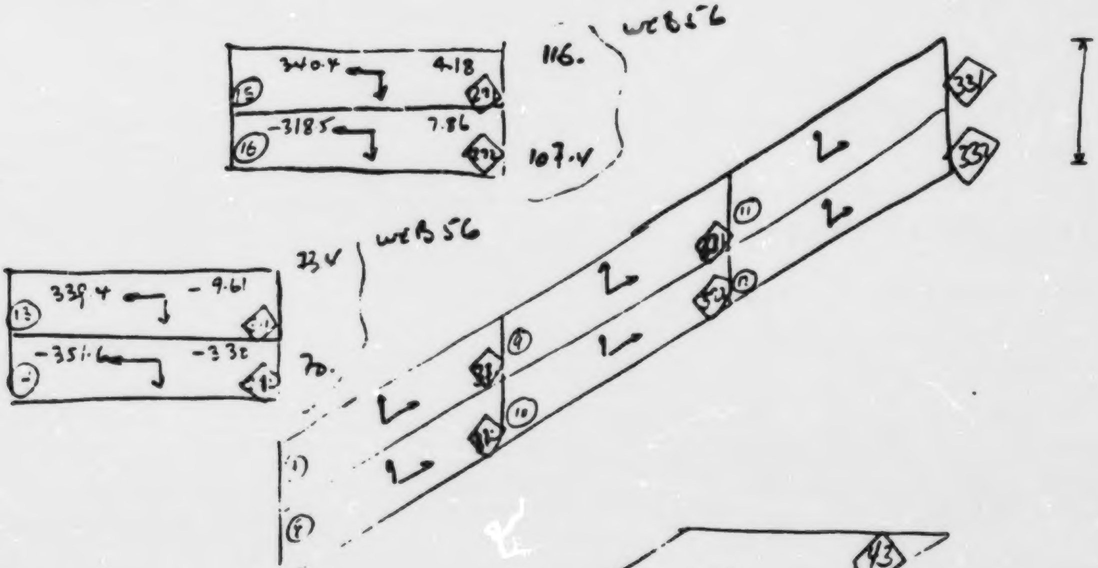
.036



13
683.3
(2)
12
673.6
(2)
11
683.3
(1)
339.4
-9.61
(19)
-351.6
-3.30
(20)
340.4
4.18
(17)
-318.5
7.86
(18)

rings

.036



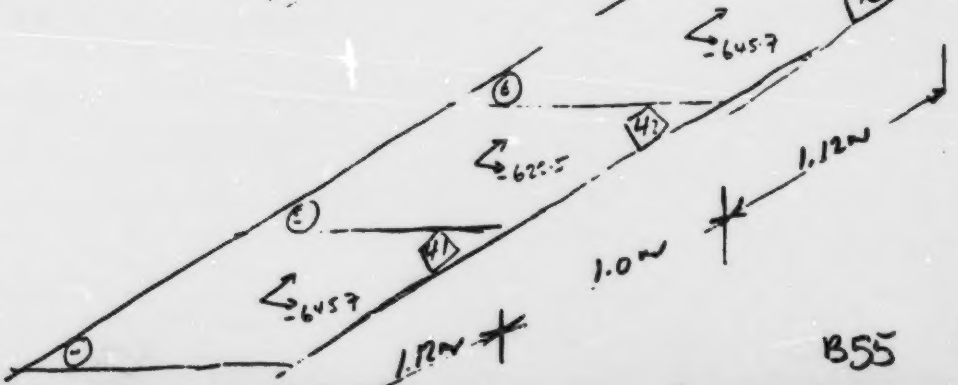
340.4
4.18
(15)
-318.5
7.86
(16)
116.
107.4
WEB 56
339.4
-9.61
(13)
-351.6
-3.30
33.4
70.
WEB 56
33
35
(11)
(12)
(9)
(10)
(7)
(8)

web

.036

outer shell

.036



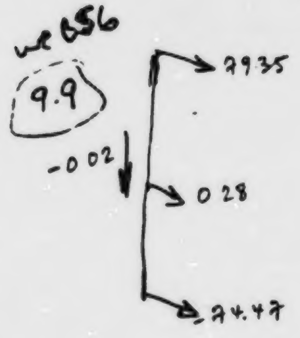
43
-645.7
(6)
42
-622.5
(5)
41
-645.7
1.12W
1.0W
1.12W

CALCULATION SHEET

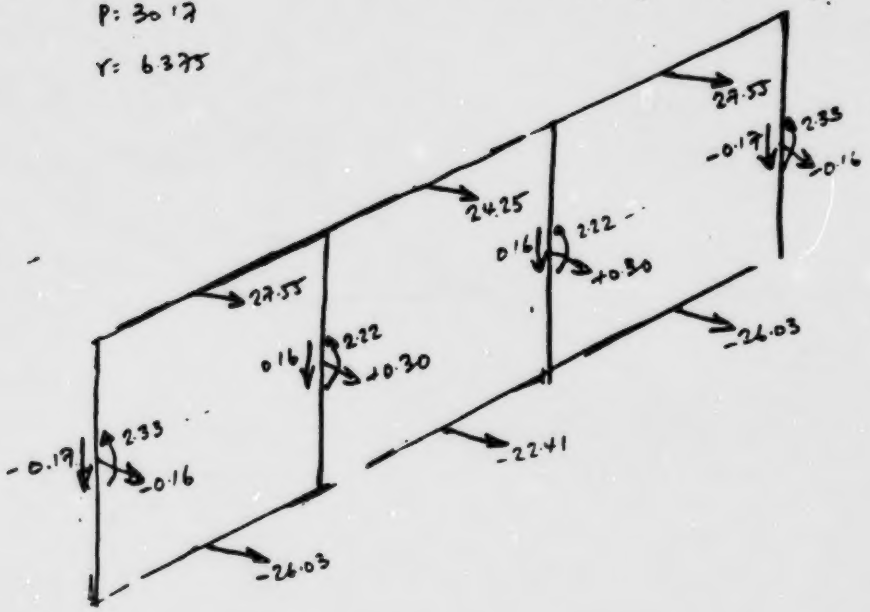
WEB No. 55

P: 30.7

r: 6.375


web56
9.9
79.35
-0.02
0.28
-74.47

Sum of forces.


27.55
2.33
-0.17
-0.16
24.25
2.22
0.16
+0.30
27.55
-26.03
2.22
0.16
+0.30
-22.41
2.33
-0.17
-0.16
-26.03

Forces.

$N = 79.35 + 0.28 - 74.47 = 5.16$

$M_2 = (2.33 + 2.22)\times 2 = 9.10$

$V = -0.02$

$M = [79.35 - (-74.47)] \times 0.5 \times .75 + (9.10) = 66.78$

SAP IV	DOME	web56 V=9.0	web54 V=[illegible]
$\frac{N}{F}$ = 0.135	0.165		
$\frac{V}{P}$ = 0	-0.769	0.260	-0.510
$\frac{M}{Fr}$ = 0.74	0.28		

CALCULATION SHEET

RUN# 1

WEB No. 64

El. no. = 1260 + ⓘ

thickness = ☐

Inner shell

.036

rings

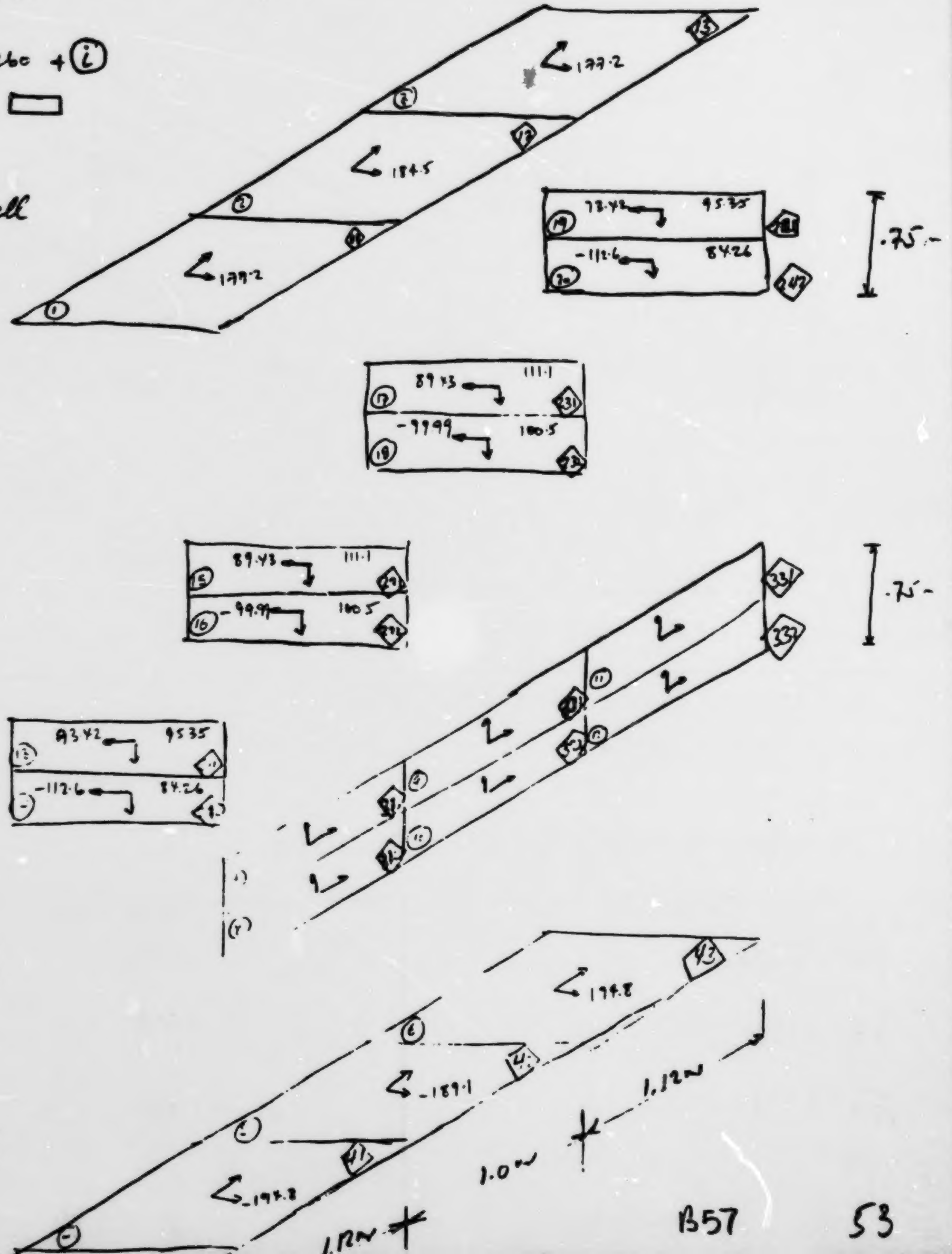
.036

WEB

.036

Outer shell

.036



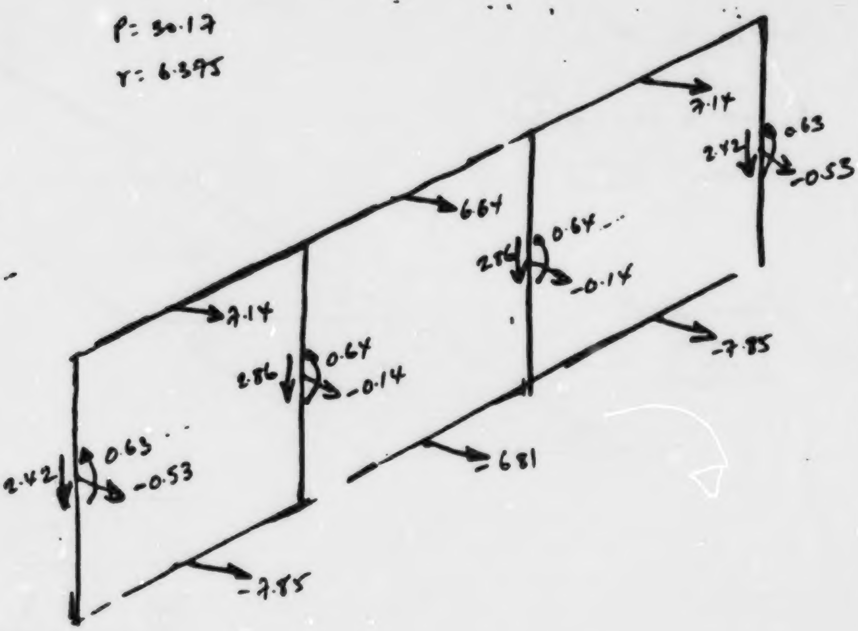
23
177.2
3
17
184.5
2
16
179.2
1
73.42
95.35
19
-112.6
84.26
20
.75
89.43
111.1
17
-99.99
100.5
18
31
32
89.43
111.1
15
-99.99
100.5
16
33
35
.75
11
93.42
95.35
13
-112.6
84.26
43
197.8
6
-189.1
1.12W
1.0W
-197.8

CALCULATION SHEET

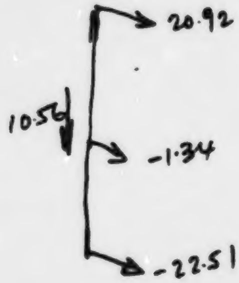
WEB No. 64

$P = 30.17$

$r = 6.395$


7.14
0.63
2.42
-0.53
6.64
0.64
2.86
-0.14
7.14
0.64
2.86
-0.14
-7.85
0.63
2.42
-0.53
681
-7.85

Forces.


20.92
10.56
-1.34
-22.51

Sum of forces.

$N = 2092 - 1.34 - 22.51 = -2.93$

$m_2 = (0.63 + 0.64) \times 2 = 2.54$

$V = 10.56$

$M = [(20.92) - (-22.51)] \times 0.5 \times .75 + 2.54 = 18.83$

	SAP IV	DOME
$\frac{N}{P}$ =	-0.077	-0.058
$\frac{V}{P}$ =	0.277	0.269
$\frac{M}{Pr}$ =	0.077	0.092

DOME PETROLEUM LIMITED

CALCULATION SHEET

TITLE PROJECT NO77 LF STRENGTH – OUTPUT CALCULATN FOR DIFFERENT RUN

DATE

PREPARED BY

CHECKED BY

RUN# 1

P = 38.17

Y = 6375

WEB#	N	M_1	V	M	$\frac{N}{P}$	$\frac{V}{P}$	$\frac{M}{PR}$
1	-9.36	-2.94	-5.47	-21.72	-0.245	-0.144	-0.0
10	-10.43	-3.84	-2.82	-28.47	-0.273	-0.074	-0.11
19	-5.53	0.34	-9.44	2.52	-0.145	-0.247	0.0
28	2.55	7.14	-10.56	53.07	0.067	-0.277	0.2
33	6.61	11.02	-8.18	78.83	0.173	-0.214	0.32
40	-25.1	-16.86	-14.02	-120.8	-0.658	-0.367	-0.4
46	-14.85	-7.56	-25.18	-52.09	-0.389	-0.660	-0.
55	5.16	9.10	-0.02	66.78	0.135	0	0.2
64	-2.93	2.54	10.56	18.83	-0.077	0.277	0.02

COST CENTRE
OR AFE No.

DOME PETROLEUM LIMITED

CALCULATION SHEET

TITLE/PROJECT RUN# 1

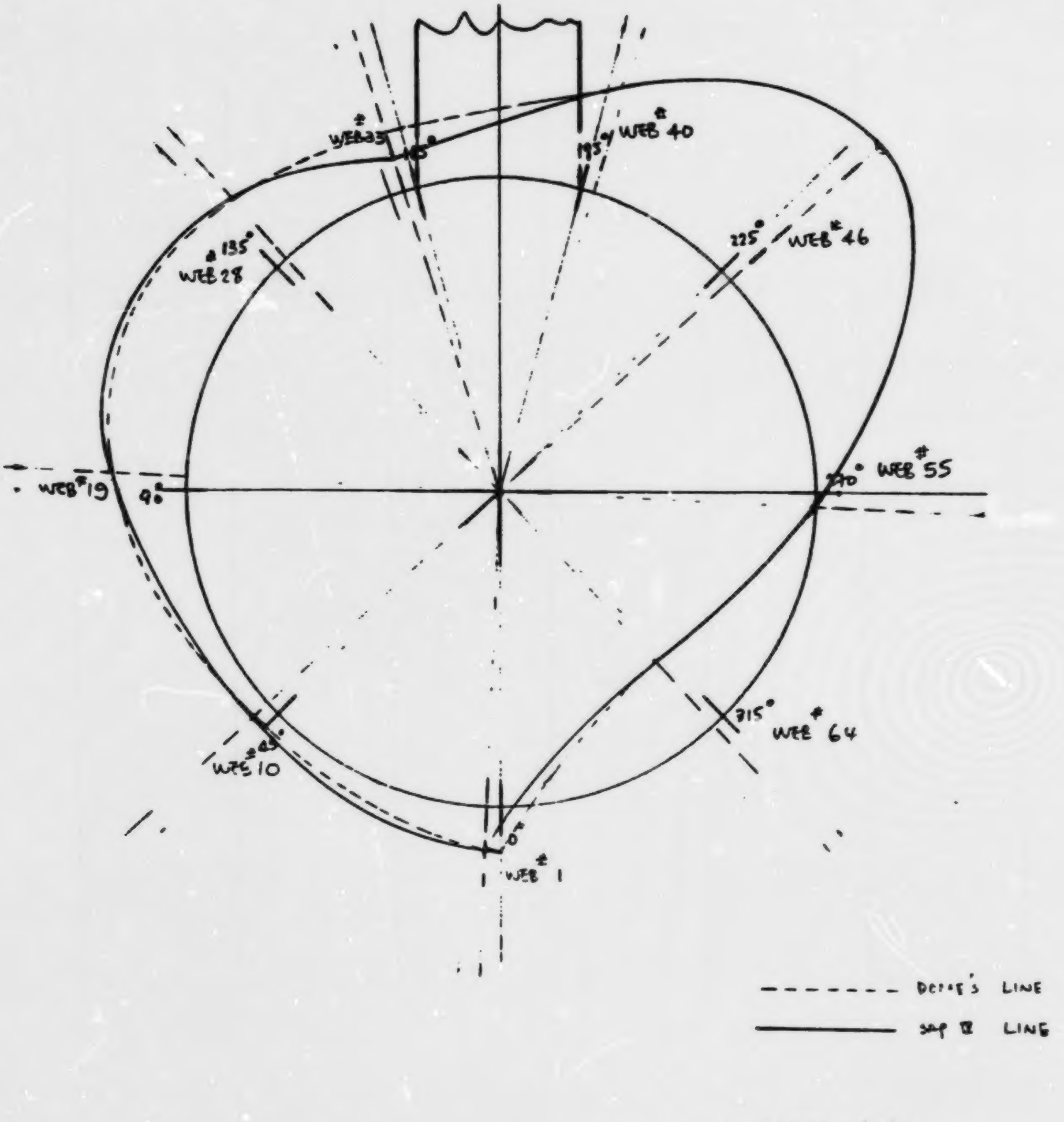
DATE YEAR MONTH DAY

PREPARED BY

CHECKED BY

$\frac{V}{P}$ PLOT.

R = 6.375 M.
P = 38.17 MN


WEB#35
165°
195°
WEB#40
#135°
WEB 28
225°
WEB#46
WEB#19
90°
270°
WEB#55
45°
WEB 10
315°
WEB#64
0°
WEB#1
DOME'S LINE
SAP II LINE

SCALE : 1:20

COST CENTRE
DRAWN

DOME PETROLEUM LIMITED
CALCULATION SHEET

TITLE PROJECT RUN# 1

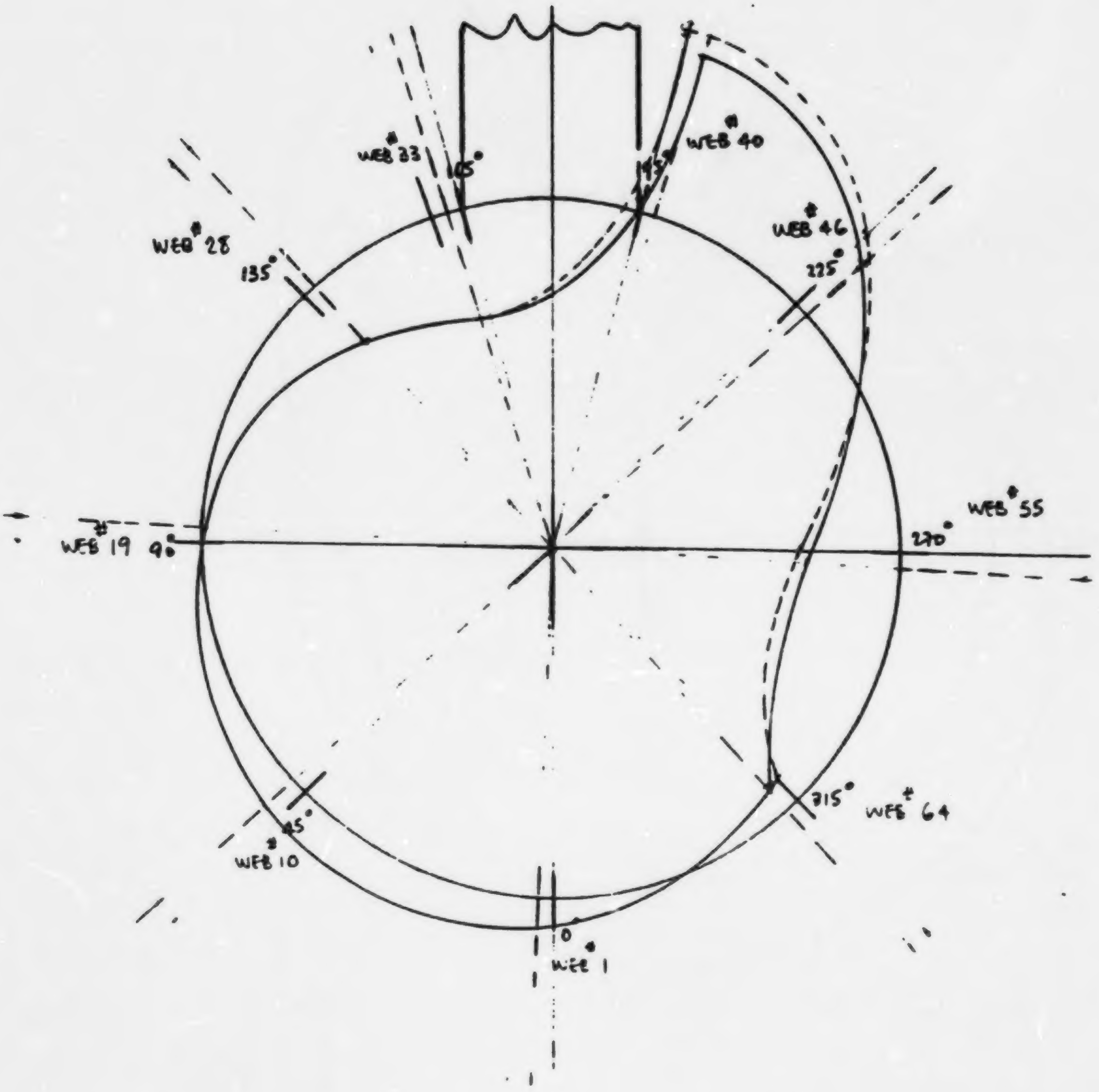
DATE YEAR MONTH DAY

PREPARED BY

CHECKED BY

$\frac{PA}{PR}$ PLOT

R = 6.375 m
P - 38.17 MN


WEB# 33
165°
195°
WEB# 40
WEB# 28
135°
WEB# 46
225°
WEB 19
90°
WEB# 55
270°
315°
WEB# 64
45°
WEB# 10
0
WEB# 1

- - - - DOME'S LINE
———— SAP IV LINE

SCALE 1:20

BG1 57

[illegible]

DOME PETROLEUM LIMITED
CALCULATION SHEET

TITLE/PROJECT RUN# 1

DATE

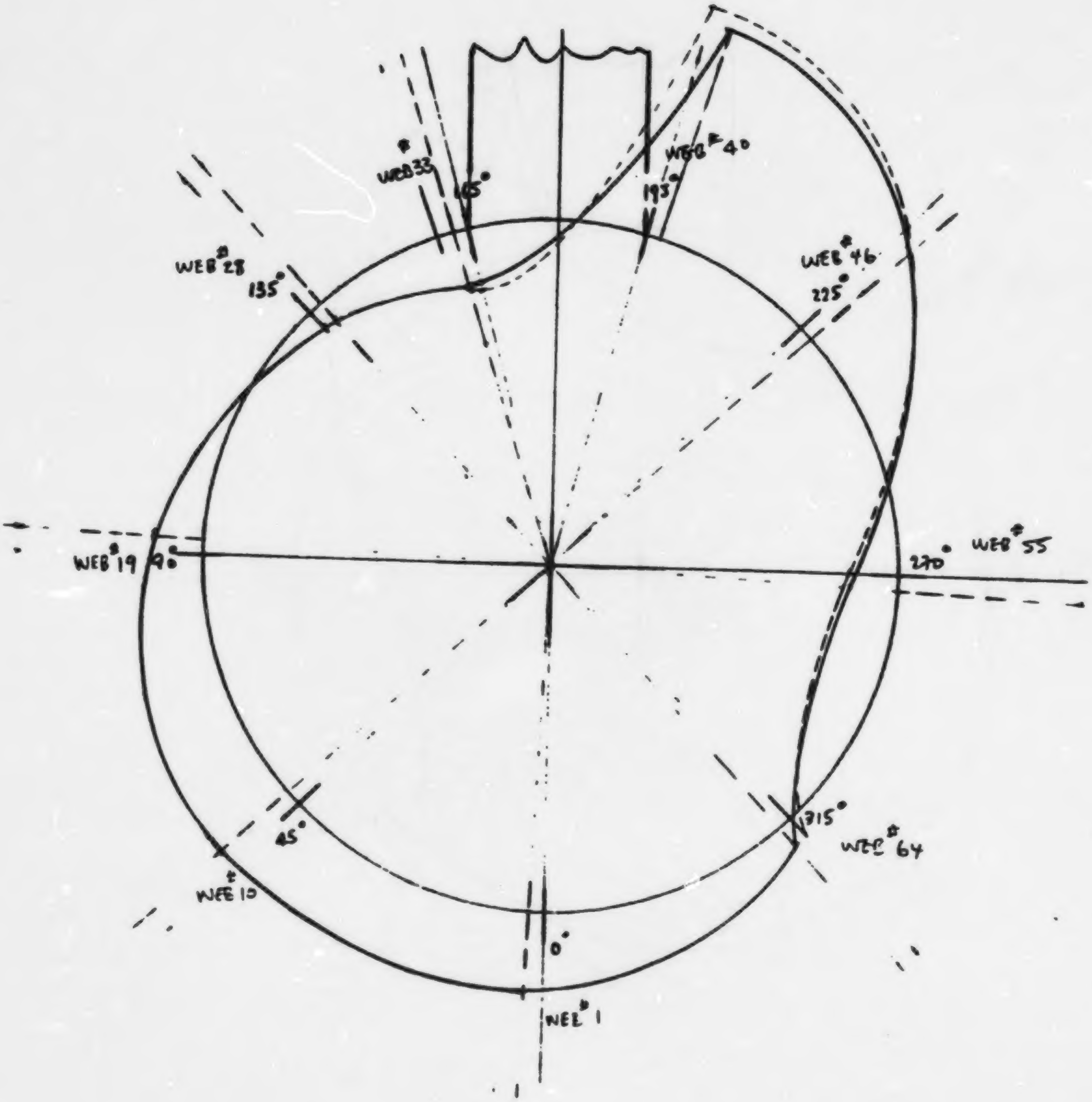
PREPARED BY

CHECKED BY

R = 6.375 m

P = 38.17 MN.

$\frac{N}{P}$ PLOT



----- DOME'S LINE

—— SAP IV LINE

SCALE: 1:20

B62 58

FEM RUNS OUTPUT SUMMARY

TABLE B.2

FEM RUNS OUTPUT SUMMARY

RUN NUMBER 1 P = 38.17 Y = 6.375

Web No.	N	M_2	V	M	N/P	V/P	M/PR
1	-9.36	-2.94	-5.47	-21.72	-0.245	+0.144	-0.089
10	-10.43	-3.84	-2.82	-28.47	-0.273	-0.074	-0.117
19	-5.53	0.34	-9.44	2.52	-0.145	-0.247	0.010
28	2.55	7.14	-10.56	53.07	0.067	-0.277	0.218
33	6.61	11.02	-8.18	78.83	0.173	-0.214	0.324
40	-25.10	-16.86	-14.02	-120.80	-0.658	-0.367	-0.496
46	-14.85	-7.56	-25.18	-56.09	-0.389	-0.660	-0.231
55	5.16	9.10	-0.02	66.78	0.135	0.000	0.274
64	-2.93	2.54	10.56	18.83	-0.077	0.277	0.077

RUN NUMBER 2 P = 20.36 Y = 3.3

Web No.	N	M_2	V	M	N/P	V/P	M/PY
1	5.12	-0.66	2.70	-5.93	-0.251	0.133	-0.088
10	-5.70	-0.84	-1.46	-7.64	-0.280	-0.072	-0.114
19	-2.91	0.08	-4.76	0.75	-0.143	-0.234	0.011
28	1.59	1.58	-5.32	14.33	0.078	-0.261	0.213
33	3.74	2.54	-3.66	21.21	0.184	-0.180	0.316
40	-13.44	-3.72	-6.42	-31.61	-0.660	-0.315	-0.470
46	-7.94	-1.62	-12.50	-14.58	-0.390	-0.614	-0.217
55	2.93	2.04	0.04	17.80	0.144	0.002	0.265
64	-1.53	0.54	5.32	4.91	-0.075	0.261	0.073

TABLE B.2 (Continued)

FEM RUNS OUTPUT SUMMARY

RUN NUMBER 3   P = 21.21   Y = 3.375

Web No.	N	M_2	V	M	N/P	V/P	M/PR
1	5.41	-0.94	3.04	6.88	-0.255	0.143	0.096
10	-5.98	-1.18	1.64	-8.81	-0.282	-0.077	-0.123
19	-3.09	0.10	-5.36	0.85	-0.146	-0.253	0.012
28	1.57	2.24	-5.96	16.51	0.074	-0.281	0.231
33	4.02	3.58	-4.30	24.43	0.190	-0.203	0.341
40	-14.13	-5.18	-7.40	-35.90	-0.666	-0.349	-0.502
46	-8.27	-2.22	-13.88	-16.41	-0.390	-0.654	-0.229
55	3.03	2.82	0.10	20.38	0.143	0.005	0.285
64	-1.67	0.74	5.98	5.57	-0.079	0.282	0.078

RUN NUMBER 4   P = 22.05   Y = 3.45

Web No.	N	M_2	V	M	N/P	V/P	M/PV
1	-5.65	-1.16	3.18	-7.35	-0.256	0.144	-0.097
10	-6.24	-1.48	-1.72	-7.12	-0.283	-0.078	-0.094
19	0.51	0.14	-5.60	-0.747	0.023	-0.254	-0.010
28	1.70	2.78	-6.22	17.564	0.077	-0.282	0.231
33	4.17	4.52	-4.60	26.06	0.189	-0.209	0.343
40	-14.69	-6.46	-7.88	-38.14	0.666	-0.357	-0.501
46	-8.61	-2.76	-14.44	-17.44	-0.390	-0.655	-0.229
55	3.20	3.52	0.12	21.65	0.145	0.005	0.285
64	1.73	0.92	6.22	5.88	-0.078	0.282	0.077

TABLE B.2 (Continued)

FEM RUNS OUTPUT SUMMARY

RUN NUMBER 5   P = 21.21   Y = 3.375

Web No.	N	M_2	V	M	N/P	V/P	M/PR
1	-0.79	2.68	5.20	19.32	-0.037	0.245	0.270
10	-8.01	-0.52	6.88	-3.81	-0.378	0.324	-0.053
19	-10.55	-1.66	-0.78	-12.25	-0.497	-0.037	-0.171
28	-2.71	-0.04	-7.98	-1.79	-0.128	-0.376	-0.025
33	-2.91	1.88	-9.92	13.15	-0.137	-0.468	0.184
40	-2.91	1.90	7.92	13.18	-0.137	+0.373	0.184
46	-7.59	-0.34	7.34	-2.43	-0.358	0.346	-0.034
55	-10.60	-1.68	-0.16	-12.35	-0.500	-0.008	-0.173
64	-7.37	-0.24	-7.56	-1.71	-0.347	-0.356	-0.024

RUN NUMBER 6   P = 17.67   Y = 3.375

Web No.	N	M_T	M_Y	V/P	MT/PR	MY/PR
1	-1.11	1.19	-24.94	-0.063	0.020	-0.418
10	-8.82	14.33	-0.68	-0.499	0.240	-0.011
19	-8.81	1.95	27.72	-0.499	0.033	0.465
28	-8.81	-28.92	38.94	-0.499	-0.485	0.670
33	-8.71	-47.17	36.00	-0.493	-0.791	0.604
40	8.75	47.62	36.00	0.495	0.799	0.604
46	8.81	25.16	39.76	0.499	0.422	0.667
55	8.81	-4.52	25.18	0.499	-0.076	0.422
64	8.82	-14.15	-4.10	0.499	-0.237	-0.069

TABLE B.2 (Continued)

FEM RUNS OUTPUT SUMMARY

RUN NUMBER 7   P = 17.67   Y = 3.375

Web No.	N	M_T	M_Y	V/P	MT/PR	MY/PR
1	-1.10	1.15	-24.47	-0.062	0.019	-0.410
10	-8.80	13.94	-0.45	-0.498	0.234	-0.008
19	-8.81	1.51	27.63	-0.499	0.025	0.463
28	-8.80	-29.15	39.55	-0.498	-0.489	0.663
33	8.77	-47.04	35.65	-0.496	-0.789	0.598
40	8.80	47.41	45.34	0.498	0.795	0.760
46	8.83	25.65	37.01	0.500	0.430	0.621
55	8.77	-3.91	25.24	0.496	-0.066	0.423
64	8.85	-13.80	-3.68	0.501	-0.231	-0.062

RUN #8   Web No. for this Run ≠ Web No.for Other Runs

P = 21.21   R = 3.375   Web No. = 8/10 +1

Web No	8	N	M_2	V	M	N/P	V/P	M/PR
1	0	-2.38	2.08	5.08	15.06	-0.112	0.240	0.210 *
5	40	8.34	-0.42	6.50	-3.07	-0.393	0.306	-0.043
	45					-0.416	0.270	-0.066 *
6	50	-9.30	-0.84	4.96	-6.28	-0.438	+0.234	-0.088
10	90	-10.29	-1.30	-2.18	-9.56	-0.485	-0.103	-0.134 *
14	130	-6.61	0.36	-8.30	2.70	-0.312	-0.391	0.038
	135					-0.276	-0.416	0.073 *
15	140	-5.10	1.10	-9.34	7.69	-0.240	-0.440	0.107
17	160	7.46	0.68	2.20	5.26	0.352	0.104	0.073

TABLE B.2 (Continued)

FEM RUNS OUTPUT SUMMARY

RUN #8 Web No. for this Run ≠ Web No.for Other Runs

$P = 21.21$ $R = 3.375$ Web No. = $\theta/10 + 1$

Web No	θ	N	M_2	V	M	N/P	V/P	M/PR
20	190	7.85	0.76	-2.24	5.27	0.370	-0.106	0.074
	195					0.349	-0.116	0.089 *
21	200	6.94	1.02	-2.68	7.48	0.327	-0.126	0.104
22	210	-5.09	1.12	9.34	7.70	-0.240	0.440	0.108
23	220	-6.60	0.36	8.30	2.69	-0.311	0.391	0.038
	225					0.342	0.362	0.008 *
24	230	-7.88	-0.22	7.04	-1.62	-0.372	0.332	-0.023
28	270	-10.51	-1.40	0.34	-10.27	-0.496	0.016	-0.143 *
32	310	-8.35	-0.42	-6.50	-3.06	-0.394	-0.306	-0.043
	315					-0.366	-0.338	-0.015 *
33	320	-7.14	0.12	-7.84	0.97	-0.337	-0.370	0.014

PROGRAM LISTING

```
            NK3  = NWEBF +        NBOT    + NWF *     ( NXF - 1 )
C
            DO 14  K = 1 , 2
            KB1 = ( 2 * NXF - 1 ) * NWEBF * ( K - 1 ) + NPRG
            KA1 =                   NK1   * ( K - 1 ) + NBOT
            JB1 = 1
            IF ( K .EQ. 2 ) JB1 = NXF2
            IC = O
            DO 13 J = 1 , NWEBF
            JWF = IWEBF ( J )
            IF ( J .EQ. JWF ) IC = IC + 1
            IB1 = J + KB1
            DO 12 IZ = 1 , NZF
            IA1 = NADF * ( IZ - 1 ) + KA1 + J
            X ( IA1 ) = XFOUND ( JB1 )
            Y ( IA1 ) = Y ( IB1 )
            Z ( IA1 ) = ZF ( IZ )
            IF ( IWDD4 .NE. O ) WRITE ( IW , 102 )
     1         K,J,IB1,IZ,IA1,X(IA1),Y(IA1),Z(IA1)
            IF ( J .NE. JWF ) GO TO 11
            J2 = 1
            IF ( K .EQ. 2 ) J2 = 2 * NXF + NRING
            IFOUN ( IC , IZ + 1 , J2 ) = IA1
         11 CONTINUE
         12 CONTINUE
         13 CONTINUE
         14 CONTINUE
C
C           NODES BETWEEN DIAG. AND RINGS
C
            DO 24  K = 1 , 2
            KB2 = ( NXF - 1 ) * NWEBF * ( K - 1 ) + NPRG
            KA2 = NBOT +        NK2   * ( K - 1 ) + NWEBF
            DO 23 IX = 2 , NXF
            J2 = IX + ( K - 1 ) * ( NXF + NRING - 1 )
            JB2 = IX + ( K - 1 ) * ( NXF - 1 )
            DO 22 J = 1 , NWF
            IB2 = J * NWDD - 1 + KB2 + NWEBF * ( IX - 1 )
            DO 21 IZ = 1 , NZF
            IA2 = NADF * ( IZ - 1 ) + KA2 + J + NWF * ( IX - 2 )
            X ( IA2 ) = XFOUND ( JB2 )
            Y ( IA2 ) = Y ( IB2 )
            Z ( IA2 ) = ZF ( IZ )
            IF ( IWDD4 .NE. O ) WRITE ( IW , 103 )
     1         K,IX,J,IB2,IZ,IA2,X(IA2),Y(IA2),Z(IA2)
            IFOUN ( J , IZ + 1 , J2 ) = IA2
         21 CONTINUE
         22 CONTINUE
         23 CONTINUE
         24 CONTINUE
C
C           NODES ABOVE RINGES
C
            DO 34  L = 1 , NRING
            KA3 = NK3 + ( L - 1 ) * NWEBF
            IC = O
            DO 33 J = 1 , NWEBF
            JWF = IWEBF ( J )
            IF ( J .EQ. JWF ) IC = IC + 1
            L1 = NWFS + J - 1
            LD = IWEB ( L1 )
            KB3 = 3 * NRING * ( LD - 1 )
            IB3 = KB3 + 3 * L
            DO 32 IZ = 1 , NZF
            IA3 = NADF * ( IZ - 1 ) + KA3 + J
            X ( IA3 ) = X ( IB3 )
            Y ( IA3 ) = Y ( IB3 )
            Z ( IA3 ) = ZF ( IZ )
            IF ( IWDD4 .NE. O ) WRITE ( IW , 104 )
          1     L,J,L1,LD,IB3,IZ,IA3,X(IA3),Y(IA3),Z(IA3)
            IF ( J .NE. JWF ) GO TO 31
            J2 = L + NXF
            IFOUN ( IC , IZ + 1 , J2 ) = IA3
         31 CONTINUE
         32 CONTINUE
         33 CONTINUE
         34 CONTINUE
      C
            IF ( IWDD4 .EQ. O ) RETURN
      C
            WRITE ( IW , 202 )
            DO 51 J = 1 , NZF1
            DO 51 K = 1 , NXNR
            WRITE ( IW , 105 ) J,K,(IFOUN(I,J,K),I=1,NWF)
         51 CONTINUE
      C
        101 FORMAT(1H ,22H I L LD N J J1 X Y Z  ,       6I5,3F10.5)
        102 FORMAT(1H ,23H K J IB1 IZ IA1 X Y Z  ,      5I5,3F10.5)
        103 FORMAT(1H ,26H K IX J IB2 IZ IA2 X Y Z  ,   6I5,3F10.5)
        104 FORMAT(1H ,29H L J L1 LD IB3 IZ IA3 X Y Z  ,7I5,3F10.5)
        105 FORMAT(1H ,20I5)
      C
        201 FORMAT(1H ,25HCOORDINATES OF FOUNDATION,/)
        202 FORMAT(1H ,30HTOPOLOGY OF WEBS IN FOUNDATION,/)
      C
            RETURN
            END
```

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FORTRAN IV G1  RELEASE 2.0           COR2              DATE = 84327          01/49/16               PAGE 0004

   *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
   *OPTIONS IN EFFECT*  NAME = COR2     , LINECNT =       60
   *STATISTICS*    SOURCE STATEMENTS =        121,PROGRAM SIZE =      4272
   *STATISTICS*  NO DIAGNOSTICS GENERATED
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```
FORTRAN IV G1  RELEASE 2.0          TOP1              DATE = 84327          01/49/16              PAGE 0001
 0001                    SUBROUTINE TOP1 ( IWEB,INOD,
                        1                   NWEB,NELEM,NRING,IW,IWDD5 )
                 C
 0002                    IMPLICIT REAL*8 (A-H,O-Z)
                 C
                 C
                 C       TOPOLOGY OF RINGS ONLY
                 C
 0003                    COMMON /GT1/ A ( 1 )
                 C
 0004                    DIMENSION IWEB(NWEB)
 0005                    DIMENSION INOD(4,NELEM)
                 C
 0006                    IF ( IWDD5 .NE. 0 ) WRITE ( IW , 201 )
                 C
 0007                    NT1  = 6 * NRING - 4
 0008                    NR1  = NRING - 1
 0009                    NERG = NT1 * NWEB
                 C
 0010                    DO 4 L = 1 , NWEB
 0011                    LD   = IWEB ( L  )
 0012                    L1   = L + 1
 0013                    IF ( L1 .GT. NWEB ) L1 = 1
 0014                    LD1 = IWEB ( L1 )
 0015                    JLD  = 3 * NRING * ( LD  - 1 )
 0016                    JLD1 = 3 * NRING * ( LD1 - 1 )
 0017                    LL   = NT1 * ( L - 1 )
 0018                    IF ( IWDD5 .NE. 0 ) WRITE ( IW , 101 )
                        1     L,LD,L1,LD1,JLD,JLD1,LL
 0019                    DO 3 I = 1 , NR1
 0020                    K = I
 0021                    K1 = K + 1
                 C
                 C       INNER SHELL
                 C
 0022                    IE = LL + I
 0023                    INOD ( 1 , IE ) = JLD1 + 3 * K1 - 2
 0024                    INOD ( 2 , IE ) = JLD  + 3 * K1 - 2
 0025                    INOD ( 3 , IE ) = JLD  + 3 * K -2
 0026                    INOD ( 4 , IE ) = JLD1 + 3 * K -2
                 C
                 C       OUTER SHELL
                 C
 0027                    IE = LL + I + NR1
 0028                    INOD ( 1 , IE ) = JLD1 + 3 * K1
 0029                    INOD ( 2 , IE ) = JLD  + 3 * K1
 0030                    INOD ( 3 , IE ) = JLD  + 3 * K
 0031                    INOD ( 4 , IE ) = JLD1 + 3 * K
                 C
 0032                    DO 1 J = 1 , 2
 0033                    JJ = J + 1 - 3
                 C
                 C       WEB
                 C
 0034                    IE = LL + 2 * NR1 + 2 * ( I - 1 ) + J
 0035                    INOD ( 1 , IE ) = JLD  + 3 * K1 + JJ
 0036                    INOD ( 2 , IE ) = JLD  + 3 * K  + JJ
 0037                    INOD ( 3 , IE ) = JLD  + 3 * K  + JJ - 1
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FORTRAN IV G1  RELEASE 2.0          TOP1            DATE = 84327         01/49/16              PAGE 0002

 0038                     INOD ( 4 , IE ) = JLD  + 3 * K1 + JJ - 1
                    C
                    C     RING
                    C
 0039                     IE = LL + 4 * NR1 + 2 * ( I - 1 ) + J
 0040                     INOD ( 1 , IE ) = JLD   + 3 * I  + JJ - 1
 0041                     INOD ( 2 , IE ) = JLD1  + 3 * I  + JJ - 1
 0042                     INOD ( 3 , IE ) = JLD1  + 3 * I  + JJ
 0043                     INOD ( 4 , IE ) = JLD   + 3 * I  + JJ
 0044                   1 CONTINUE
                    C
                    C     LAST RING
                    C
 0045                     IE1 = LL + 4 * NR1 + 2 * ( NRING - 1 )
 0046                     DO 2 J = 1 , 2
 0047                     JJ = J + 1 - 3
 0048                     IE = IE1 + J
 0049                     INOD ( 1 , IE ) = JLD  + 3 * NRING + JJ -1
 0050                     INOD ( 2 , IE ) = JLD1 + 3 * NRING + JJ -1
 0051                     INOD ( 3 , IE ) = JLD1 + 3 * NRING + JJ
 0052                     INOD ( 4 , IE ) = JLD  + 3 * NRING + JJ
 0053                   2 CONTINUE
 0054                   3 CONTINUE
 0055                   4 CONTINUE
                    C
 0056                     IF ( IWDD5 .EQ. 0 ) RETURN
                    C
 0057                     DO 10 I = 1 , NERG
 0058                     WRITE ( IW , 102 ) I,(INOD(J,I),J=1,4)
 0059                  10 CONTINUE
                    C
 0060                 101 FORMAT(1H ,24H L LD L1 LD1 JLD JLD1 LL,7I5)
 0061                 102 FORMAT(1H ,5I5)
 0062                 201 FORMAT(1H ,22HTOPOLOGY OF RINGS ONLY,/)
                    C
 0063                     RETURN
 0064                     END
```

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FORTRAN IV G1  RELEASE 2.0              TOP1                DATE = 84327           01/49/16                  PAGE 0003

   *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
   *OPTIONS IN EFFECT*  NAME = TOP1      , LINECNT =       60
   *STATISTICS*    SOURCE STATEMENTS =          64,PROGRAM SIZE =       2232
   *STATISTICS*  NO DIAGNOSTICS GENERATED
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FORTRAN IV G1  RELEASE 2.0              TOP2              DATE = 84327          01/49/16              PAGE 0001
 0001                   SUBROUTINE TOP2 ( IWEB,INOD,IFOUN,
                       1                  NWEB,NELEM,NWF,NZF1,NXNR,
                       2                  NXF,NWEBF,NPRG,NERG,NRING,NWFS,
                       3                  IW,IWDD6 )
                 C
 0002                   IMPLICIT REAL*8 (A-H,O-Z)
                 C
                 C
                 C      TOPOLOGY OF FOUNDATION
                 C
 0003                   COMMON /GT1/ A ( 1 )
                 C
 0004                   DIMENSION IWEB(NWEB)
 0005                   DIMENSION INOD(4,NELEM)
 0006                   DIMENSION IFOUN(NWF,NZF1,NXNR)
                 C
 0007                   NXF2 = 2 * NXF
 0008                   NWB1 = NWEBF - 1
 0009                   NXF1 = NXF + 1
 0010                   NZF  = NZF1 - 1
                 C
                 C      FOUNDATION PLATE
                 C
 0011                   DO 2 I = 1 , NXF2
 0012                   II = I
 0013                   IF ( I .GE. NXF1 ) II = I - 1
 0014                   KB1 = NPRG +   II        * NWEBF
 0015                   KB2 = KB1
 0016                   KB3 = NPRG + ( II - 1 ) * NWEBF
 0017                   KB4 = KB3
 0018                   KE  = NERG + ( NWEBF - 1 ) * ( I - 1 )
 0019                   DO 1 J = 1 , NWB1
 0020                   J1 = KB1 + J + 1
 0021                   J2 = KB2 + J
 0022                   J3 = KB3 + J
 0023                   J4 = KB4 + J + 1
 0024                   L  = NWFS + J - 1
 0025                   LD  = IWEB ( L  )
 0026                   L1  = L + 1
 0027                   IF ( L1 .GT. NWEB ) L1 = 1
 0028                   LD1 = IWEB ( L1 )
 0029                   IF ( I .EQ. NXF  ) J1 = 3 * NRING * ( LD1 - 1 ) + 3
 0030                   IF ( I .EQ. NXF  ) J2 = 3 * NRING * ( LD  - 1 ) + 3
 0031                   IF ( I .EQ. NXF1 ) J3 = 3 * NRING *   LD
 0032                   IF ( I .EQ. NXF1 ) J4 = 3 * NRING *   LD1
 0033                   IE = KE + J
 0034                   INOD ( 1 , IE ) = J1
 0035                   INOD ( 2 , IE ) = J2
 0036                   INOD ( 3 , IE ) = J3
 0037                   INOD ( 4 , IE ) = J4
 0038                   IF ( IWDD6 .NE. 0 ) WRITE ( IW , 101 )
                       1     I,KE,J,IE
 0039                 1 CONTINUE
 0040                 2 CONTINUE
                 C
                 C      DIAPHRAGMS
                 C
 0041                   NEBOT = NERG + ( NWEBF - 1 ) * 2 * NXF
```

```
      NBOT  = NPRG + 2 * NXF * NWEBF
      NADF  = NWEBF * ( 2 + NRING ) + NWF * 2 * ( NXF - 1 )
C
      DO 13 K = 1 , 2
      IE1 = NEBOT + ( NWEBF - 1 ) * NZF * ( NRING + 1 ) * ( K - 1 )
      KB1 = NPRG + ( 2 * NXF - 1 ) * NWEBF * ( K - 1 )
      KA1 = NBOT + ( NWF * 2 * ( NXF - 1 ) +
     1               NWEBF * ( NRING + 1 ) ) * ( K - 1 )
      DO 12 J = 1  , NWB1
      IB1 = KB1 + J
      IB2 = KB1 + J + 1
      DO 11 IZ = 1 , NZF
      IA1 = KA1 + NADF * ( IZ - 2 ) + J
      IA2 = KA1 + NADF * ( IZ - 2 ) + J + 1
      IA3 = KA1 + NADF * ( IZ - 1 ) + J + 1
      IA4 = KA1 + NADF * ( IZ - 1 ) + J
      IE = IE1 + ( NWEBF - 1 ) * ( IZ - 1 ) + J
      IF ( IZ .EQ. 1 ) IA1 = IB1
      IF ( IZ .EQ. 1 ) IA2 = IB2
      INOD ( 1 , IE ) = IA1
      INOD ( 2 , IE ) = IA2
      INOD ( 3 , IE ) = IA3
      INOD ( 4 , IE ) = IA4
      IF ( IWDD6 .NE. 0 ) WRITE ( IW , 102 )
     1    K,IE1,J,IZ,IE
   11 CONTINUE
   12 CONTINUE
   13 CONTINUE
C
C     ELEMENTS ABOVE RINGS
C
      DO 23 L = 1 , NRING
      IE1 = NEBOT + ( NWEBF - 1 ) * NZF * L
      KA3 = NBOT +  NWF * ( NXF - 1 ) + NWEBF +
     1              NWEBF * ( L - 1 )
      DO 22 J = 1  , NWB1
      LW  = NWFS + J - 1
      LD  = IWEB ( LW  )
      L1  = LW + 1
      IF ( L1 .GT. NWEB ) L1 = 1
      LD1 = IWEB ( L1 )
      IB1 = 3 * NRING * ( LD  - 1 ) + 3 * L
      IB2 = 3 * NRING * ( LD1 - 1 ) + 3 * L
      DO 21 IZ = 1 , NZF
      IA1 = KA3 + NADF * ( IZ - 2 ) + J
      IA2 = KA3 + NADF * ( IZ - 2 ) + J + 1
      IA3 = KA3 + NADF * ( IZ - 1 ) + J + 1
      IA4 = KA3 + NADF * ( IZ - 1 ) + J
      IE = IE1 + ( NWEBF - 1 ) * ( IZ - 1 ) + J
      IF ( IZ .EQ. 1 ) IA1 = IB1
      IF ( IZ .EQ. 1 ) IA2 = IB2
      INOD ( 1 , IE ) = IA1
      INOD ( 2 , IE ) = IA2
      INOD ( 3 , IE ) = IA3
      INOD ( 4 , IE ) = IA4
      IF ( IWDD6 .NE. 0 ) WRITE ( IW , 103 )
     1    L,IE1,J,IZ,IE
   21 CONTINUE
```

```
 0092              22 CONTINUE
 0093              23 CONTINUE
                C
                C     ELEMENTS IN WEBS
                C
 0094                 IE = NEBOT + ( NWEBF - 1 ) * NZF * ( 2 + NRING )
 0095                 NXNR1 = NXNR - 1
 0096                 DO 43 I = 1 , NWF
 0097                 DO 42 J = 1 , NZF
 0098                 DO 41 K = 1 , NXNR1
 0099                 IE = IE + 1
 0100                 INOD ( 1 , IE ) = IFOUN ( I , J     , K + 1 )
 0101                 INOD ( 2 , IE ) = IFOUN ( I , J     , K     )
 0102                 INOD ( 3 , IE ) = IFOUN ( I , J + 1 , K     )
 0103                 INOD ( 4 , IE ) = IFOUN ( I , J + 1 , K + 1 )
 0104              41 CONTINUE
 0105              42 CONTINUE
 0106              43 CONTINUE
                C
 0107                 IF ( IWDD6 .EQ. 0 ) RETURN
                C
 0108                 WRITE ( IW , 201 )
 0109                 DO 60 I = 1 , NELEM
 0110                 WRITE ( IW , 104 ) I,(INOD(J,I),J=1,4)
 0111              60 CONTINUE
                C
 0112             101 FORMAT(1H ,23H 101 I,KE,J,IE          ,4I5)
 0113             102 FORMAT(1H ,23H 102 K,IE1,J,IZ,IE      ,5I5)
 0114             103 FORMAT(1H ,23H 103 L,IE1,J,IZ,IE      ,5I5)
                C
 0115             104 FORMAT(1H ,5I5)
                C
 0116             201 FORMAT(1H ,14HTOPOLOGY TABLE,/)
                C
 0117                 RETURN
 0118                 END
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FORTRAN IV G1  RELEASE 2.0              TOP2                  DATE = 84327            01/49/16                 PAGE 0004

   *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
   *OPTIONS IN EFFECT*  NAME = TOP2      , LINECNT =       60
   *STATISTICS*    SOURCE STATEMENTS =       118,PROGRAM SIZE =       3940
   *STATISTICS*  NO DIAGNOSTICS GENERATED
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FORTRAN IV G1  RELEASE 2.0          THIH            DATE = 84327          01/49/16              PAGE 0001

  0001                     SUBROUTINE THIH ( ITHW,ITHWF,ITHD,THICK,
                          1                 HH,ITHR,
                          2                 NITHW,NWF,NR2,NTHIC,NELEM,NRING,
                          3                 THIS,THOS,THFP,THFPI,
                          4                 NWEB,NWEBF,NERG,NXF,NZF1,NWFS,
                          5                 NXNR,IW,IWDD7 )
                   C
  0002                     IMPLICIT REAL*8 (A-H,O-Z)
                   C
                   C
                   C       THICKNESSES OF STRUCTURE
                   C
  0003                     COMMON /GT1/ A ( 1 )
                   C
  0004                     DIMENSION ITHW(3,NITHW),ITHWF(NWF)
  0005                     DIMENSION ITHD(NR2),THICK(NTHIC)
  0006                     DIMENSION HH(NELEM)
  0007                     DIMENSION ITHR(NRING)
                   C
  0008                     IF ( IWDD7 .NE. O ) WRITE ( IW , 201 )
                   C
  0009                     NT1  = 6 * NRING - 4
  0010                     NR1  = NRING - 1
                   C
  0011                     DO 2 L = 1 , NWEB
  0012                     LL   = NT1 * ( L - 1 )
  0013                     DO 1 I = 1 , NR1
                   C
                   C       INNER SHELL
                   C
  0014                     IE = LL + I
  0015                     HH ( IE ) = THIS
  0016                     IF ( IWDD7 .NE. O ) WRITE ( IW , 101 )
                          1     L,I,IE,HH(IE)
                   C
                   C       OUTER SHELL
                   C
  0017                     IE = LL + I + NR1
  0018                     HH ( IE ) = THOS
  0019                     IF ( IWDD7 .NE. O ) WRITE ( IW , 102 )
                          1     L,I,IE,HH(IE)
                   C
  0020                   1 CONTINUE
  0021                   2 CONTINUE
                   C
                   C       WEB
                   C
  0022                     DO 14 II = 1 , NITHW
  0023                     IIS = ITHW ( 1 , II )
  0024                     IIE = ITHW ( 2 , II )
  0025                     ITY = ITHW ( 3 , II )
  0026                     DO 13 L = IIS , IIE
  0027                     LL   = NT1 * ( L - 1 )
  0028                     DO 12 I = 1 , NR1
  0029                     DO 11 J = 1 , 2
  0030                     IE = LL + 2 * NR1 + 2 * ( I - 1 ) + J
  0031                     HH ( IE ) = THICK ( ITY )
  0032                     IF ( IWDD7 .NE. O ) WRITE ( IW , 103 )
```

```
                         1      II,ITY,L,I,J,IE,HH(IE)
  0033                 11 CONTINUE
  0034                 12 CONTINUE
  0035                 13 CONTINUE
  0036                 14 CONTINUE
                  C
                  C       RING
                  C
  0037                    DO 23 L = 1 , NWEB
  0038                    LL    = NT1 * ( L - 1 )
  0039                    DO 22 I = 1 , NRING
  0040                    ITY = ITHR ( I )
  0041                    DO 21 J = 1 , 2
  0042                    IE = LL + 4 * NR1 + 2 * ( I - 1 ) + J
  0043                    HH ( IE ) = THICK ( ITY )
  0044                    IF ( IWDD7 .NE. O ) WRITE ( IW , 104 )
                         1      L,I,ITY,J,IE,HH(IE)
  0045                 21 CONTINUE
  0046                 22 CONTINUE
  0047                 23 CONTINUE
                  C
  0048                    NXF2 = 2 * NXF
  0049                    NWB1 = NWEBF - 1
  0050                    NXF1 = NXF + 1
  0051                    NZF  = NZF1 - 1
                  C
                  C       FOUNDATION PLATE
                  C
  0052                    DO 32 I = 1 , NXF2
  0053                    KE   = NERG + ( NWEBF - 1 ) * ( I - 1 )
  0054                    DO 31 J = 1 , NWB1
  0055                    IE = KE + J
  0056                    HH ( IE ) = THFP
  0057                    IF ( IWDD7 .NE. O ) WRITE ( IW , 105 )
                         1      I,J,IE,HH(IE)
  0058                 31 CONTINUE
  0059                 32 CONTINUE
                  C
                  C       DIAPHRAGMS
                  C
                  C       ELEMENTS ABOVE RINGS
                  C
  0060                    NEBOT = NERG + ( NWEBF - 1 ) * 2 * NXF
                  C
  0061                    IE = NEBOT
                  C
  0062                    DO 43 K = 1 , NR2
  0063                    ITY = ITHD ( K )
  0064                    DO 42 J = 1  , NWB1
  0065                    DO 41 IZ = 1 , NZF
  0066                    IE = IE + 1
  0067                    HH ( IE ) = THICK ( ITY )
  0068                    IF ( IWDD7 .NE. O ) WRITE ( IW , 106 )
                         1      K,ITY,J,IZ,IE,HH(IE)
  0069                 41 CONTINUE
  0070                 42 CONTINUE
  0071                 43 CONTINUE
                  C
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FORTRAN IV G1  RELEASE 2.0          THIH              DATE = 84327          01/49/16              PAGE 0003
                   C       ELEMENTS IN WEBS
                   C
 0072                      NXNR1 = NXNR - 1
                   C
 0073                      DO 53 I = 1 , NWF
 0074                      ITY = ITHWF ( I )
 0075                      DO 52 J = 1 , NZF
 0076                      DO 51 K = 1 , NXNR1
 0077                      IE = IE + 1
 0078                      HH ( IE ) = THICK ( ITY )
 0079                      IF ( IWDD7 .NE. O ) WRITE ( IW , 107 )
                         1     I,ITY,J,K,IE,HH(IE)
 0080                   51 CONTINUE
 0081                   52 CONTINUE
 0082                   53 CONTINUE
                   C
                   C       ELE. ON OUTER SHELL BET. FOUNDATIONS EDGES
                   C
 0083                      DO 62 J = 1 , NWB1
 0084                      L = NWFS + J - 1
 0085                      IE1 = NT1 * ( L - 1 ) + ( NRING - 1 )
 0086                      DO 61 I = 1 , NR1
 0087                      IE = IE1 + I
 0088                      HH ( IE ) = THFP
 0089                      IF ( IWDD7 .NE. O ) WRITE ( IW , 108 )
                         1     L,I,IE1,IE,HH(IE)
 0090                   61 CONTINUE
 0091                   62 CONTINUE
                   C
                   C       ELE. ON INNER SHELL BET. FOUNDATIONS EDGES
                   C
 0092                      DO 72 J = 1 , NWB1
 0093                      L = NWFS + J - 1
 0094                      IE1 = NT1 * ( L - 1 )
 0095                      DO 71 I = 1 , NR1
 0096                      IE = IE1 + I
 0097                      HH ( IE ) = THFPI
 0098                      IF ( IWDD7 .NE. O ) WRITE ( IW , 109 )
                         1     L,I,IE1,IE,HH(IE)
 0099                   71 CONTINUE
 0100                   72 CONTINUE
                   C
 0101                  101 FORMAT( 1H ,23H 101 L,I,IE,HH          ,3I5,F10.3)
 0102                  102 FORMAT( 1H ,23H 102 L,I,IE,HH          ,3I5,F10.3)
 0103                  103 FORMAT( 1H ,23H 103 II,ITY,L,I,J,IE,HH,6I5,F10.3)
 0104                  104 FORMAT( 1H ,23H 104 L,I,ITY,J,IE,HH    ,5I5,F10.3)
 0105                  105 FORMAT( 1H ,23H 105 I,J,IE,HH(IE)      ,3I5,F10.3)
 0106                  106 FORMAT( 1H ,23H 106 K,ITY,J,IZ,IE,HH   ,5I5,F10.3)
 0107                  107 FORMAT( 1H ,23H 107 I,ITY,J,K,IE,HH    ,5I5,F10.3)
 0108                  108 FORMAT( 1H ,23H 108 L,I,IE1,IE,HH      ,4I5,F10.3)
 0109                  109 FORMAT( 1H ,23H 109 L,I,IE1,IE,HH      ,4I5,F10.3)
                   C
 0110                  201 FORMAT(1H ,21H THICKNESSES OF STRC.,/)
                   C
                   C
 0111                      RETURN
 0112                      END
```

```
    *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
    *OPTIONS IN EFFECT*  NAME = THIH    , LINECNT =       60
    *STATISTICS*    SOURCE STATEMENTS =      112,PROGRAM SIZE =      3844
    *STATISTICS*  NO DIAGNOSTICS GENERATED
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FORTRAN IV G1  RELEASE 2.0            IDVL             DATE = 84327          01/49/16              PAGE 0001

  0001                     SUBROUTINE IDVL ( IFOUN,ID,
                         1                   NWF,NZF1,NXNR,NPOIN,
                         2                   NXF,NZF,NWEBF,NPRG,NRING,
                         3                   IW,IWDD8 )
                   C
  0002                     IMPLICIT REAL*8 (A-H,O-Z)
                   C
                   C
                   C       TYPE ID = 1 I.E. 0 0 0 0 0 0   ALL NODES EXCEPT
                   C       TYPE ID = 2 I.E. 0 0 0 0 0 1   FOUNDATION PLATE
                   C       TYPE ID = 3 I.E. 0 0 0 0 1 0   WEBS
                   C       TYPE ID = 4 I.E. 0 0 0 1 0 0   DIAPH.
                   C       TYPE ID = 5 I.E. 1 1 1 1 1 1   B. C.
                   C
  0003                     COMMON /GT1/ A ( 1 )
                   C
  0004                     DIMENSION IFOUN(NWF,NZF1,NXNR)
  0005                     DIMENSION ID(NPOIN)
                   C
  0006                     NXF1 = NXF - 1
  0007                     NXF2 = NXF + NRING + 1
  0008                     NXF3 = NXNR - 1
  0009                     NBOT  = NPRG + 2 * NXF * NWEBF
  0010                     NADF  = NWEBF * ( 2 + NRING ) + NWF * 2 * ( NXF - 1 )
                   C
                   C       ALL NODES
                   C
  0011                     DO 1 I = 1 , NPOIN
  0012                     ID ( I ) = 1
  0013                   1 CONTINUE
                   C
                   C       FOUNDATION PLATE
                   C
  0014                     IS = NPRG + NWEBF + 1
  0015                     IE = NBOT - NWEBF
  0016                     DO 11 I = IS , IE
  0017                     ID ( I ) = 2
  0018                     IF ( IWDD8 .NE. 0 ) WRITE ( IW , 101 )
                         1      I,ID(I)
  0019                  11 CONTINUE
  0020                     J = 1
  0021                     DO 14 I = 1 , NWF
  0022                     DO 12 K = 2 , NXF
  0023                     I1 = IFOUN ( I , J , K )
  0024                     ID ( I1 ) = 1
  0025                     IF ( IWDD8 .NE. 0 ) WRITE ( IW , 102 )
                         1      I,K,I1,ID(I1)
  0026                  12 CONTINUE
  0027                     DO 13 K = NXF2 , NXF3
  0028                     I1 = IFOUN ( I , J , K )
  0029                     ID ( I1 ) = 1
  0030                     IF ( IWDD8 .NE. 0 ) WRITE ( IW , 102 )
                         1      I,K,I1,ID(I1)
  0031                  13 CONTINUE
  0032                  14 CONTINUE
                   C
                   C       END DIAPHRAGMES
                   C
```

```
 0033                  NBOT = NPRG + 2 * NXF * NWEBF
 0034                  NADF = NWEBF * ( 2 + NRING ) + NWF * 2 * ( NXF - 1 )
 0035                  NK1  = NWEBF * ( 1 + NRING ) + NWF * 2 * ( NXF - 1 )
 0036                  NK3  = NWEBF +        NBOT    + NWF *     ( NXF - 1 )
                 C
 0037                  DO 23  K = 1 , 2
 0038                  KA1 = NK1   * ( K - 1 ) + NBOT
 0039                  DO 22 J = 1 , NWEBF
 0040                  DO 21 IZ = 1 , NZF
 0041                  IA1 = NADF * ( IZ - 1 ) + KA1 + J
 0042                  ID ( IA1 ) = 4
 0043                  IF ( IWDDB .NE. O ) WRITE ( IW , 103 )
                     1      K,J,IZ,IA1,ID(IA1)
 0044               21 CONTINUE
 0045               22 CONTINUE
 0046               23 CONTINUE
                 C
                 C     NODES ABOVE RINGES
                 C
 0047                  DO 26  L = 1 , NRING
 0048                  KA3 = NK3 + ( L - 1 ) * NWEBF
 0049                  DO 25 J = 1 , NWEBF
 0050                  DO 24 IZ = 1 , NZF
 0051                  IA3 = NADF * ( IZ - 1 ) + KA3 + J
 0052                  ID ( IA3 ) = 4
 0053                  IF ( IWDDB .NE. O ) WRITE ( IW , 104 )
                     1      L,J,IZ,IA3,ID(IA3)
 0054               24 CONTINUE
 0055               25 CONTINUE
 0056               26 CONTINUE
                 C
 0057                  IS = NXF + 1
 0058                  IE = NXF + NRING
                 C
 0059                  DO 29 I = 1 , NWF
 0060                  DO 28 J = 2 , NZF1
 0061                  K = 1
 0062                  I1 = IFOUN ( I , J , K )
 0063                  ID ( I1 ) = 1
 0064                  IF ( IWDDB .NE. O ) WRITE ( IW , 105 )
                     1      I,J,K,I1,ID(I1)
 0065                  DO 27 K = IS , IE
 0066                  I1 = IFOUN ( I , J , K )
 0067                  ID ( I1 ) = 1
 0068                  IF ( IWDDB .NE. O ) WRITE ( IW , 105 )
                     1      I,J,K,I1,ID(I1)
 0069               27 CONTINUE
 0070                  K = NXNR
 0071                  I1 = IFOUN ( I , J , K )
 0072                  ID ( I1 ) = 1
 0073                  IF ( IWDDB .NE. O ) WRITE ( IW , 105 )
                     1      I,J,K,I1,ID(I1)
 0074               28 CONTINUE
 0075               29 CONTINUE
                 C
                 C     WEBS
                 C
 0076                  DO 34 I = 1 , NWF
```

```
      DO 33 J = 2 , NZF1
      DO 31 K = 2 , NXF
      I1 = IFOUN ( I , J , K )
      ID ( I1 ) = 3
      IF ( IWDD8 .NE. 0 ) WRITE ( IW , 106 )
     1      I,J,K,I1,ID(I1)
   31 CONTINUE
      DO 32 K = NXF2 , NXF3
      I1 = IFOUN ( I , J , K )
      ID ( I1 ) = 3
      IF ( IWDD8 .NE. 0 ) WRITE ( IW , 106 )
     1      I,J,K,I1,ID(I1)
   32 CONTINUE
   33 CONTINUE
   34 CONTINUE
C
C
C     B. C.
C
      IS = NADF * ( NZF - 1 ) + NBOT + 1
      IE = NPOIN
C
      DO 41 I = IS , IE
      ID ( I ) = 5
      IF ( IWDD8 .NE. 0 ) WRITE ( IW , 107 )
     1      I,ID(I)
   41 CONTINUE
C
      IF ( IWDD8 .EQ. 0 ) RETURN
C
      WRITE ( IW , 201 )
      DO 60 I = 1 , NPOIN
      WRITE ( IW , 108 ) I,ID(I)
   60 CONTINUE
C
  101 FORMAT(1H ,23H 101 I,ID                ,2I5)
  102 FORMAT(1H ,23H 102 I,K,I1,ID           ,4I5)
  103 FORMAT(1H ,23H 103 K,J,IZ,IA1,ID       ,5I5)
  104 FORMAT(1H ,23H 104 L,J,IZ,IA3,ID       ,5I5)
  105 FORMAT(1H ,23H 105 I,J,K,I1,ID         ,5I5)
  106 FORMAT(1H ,23H 106 I,J,K,I1,ID         ,5I5)
  107 FORMAT(1H ,23H 107 I,ID                ,2I5)
  108 FORMAT(1H ,5I5)
C
  201 FORMAT(1H ,7HNODE ID,/)
C
      RETURN
      END
  *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
  *OPTIONS IN EFFECT*  NAME = IDVL    , LINECNT =       60
  *STATISTICS*    SOURCE STATEMENTS =       111,PROGRAM SIZE =      3724
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G1  RELEASE 2.0          PRESS            DATE = 84327          01/49/16            PAGE 0001
 0001                  SUBROUTINE PRESS ( PRES,
                     1                    NELEM,NRING,ANGW,IR,IW,IWDD9 )
                 C
 0002                  IMPLICIT REAL*8 (A-H,O-Z)
                 C
                 C
                 C     PRESSURE LOADING
                 C
 0003                  COMMON /GT1/ A ( 1 )
                 C
 0004                  DIMENSION PRES(NELEM)
                 C
 0005                  DO 1 I = 1 , NELEM
 0006                  PRES ( I ) = 0.
 0007                1 CONTINUE
                 C
 0008                  NT1  = 6 * NRING - 4
 0009                  NR1  = NRING - 1
                 C
                 C
                 C**************************************************
                 C
                 C
                 C     R E A D   F O U R T H     S E T
                 C
                 C
                 C
                 C**************************************************
                 C
 0010                  WRITE ( IW , 304 )
                 C
 0011                  READ  ( IR , 112 ) NLOAD
 0012                  WRITE ( IW , 212 ) NLOAD
                 C
 0013                  DO 40 II = 1 , NLOAD
                 C
 0014                  READ  ( IR , 113 ) ITY , THETA , PRE
 0015                  WRITE ( IW , 213 ) ITY , THETA , PRE
                 C
                 C**************************************************
                 C
 0016                  THETA = 180. + THETA
 0017                  IF ( THETA .GE. 360. ) THETA = THETA - 360.
 0018                  L = THETA / ANGW + 1
 0019                  LL = NT1 * ( L - 1 )
                 C
 0020                  GO TO ( 10 , 20 ) , ITY
                 C
 0021               10 CONTINUE
                 C
 0022                  DO 11 I = 1 , NR1
                 C
                 C     OUTER SHELL
                 C
 0023                  IE = LL + I + NR1
 0024                  PRES ( IE ) = PRE
 0025               11 CONTINUE
                 C
```

```
0026               GO TO 30
              C
0027            20 CONTINUE
              C
0028               DO 21 J = 1 , 2
              C
              C    RING
              C
0029               IE = LL + 4 * NR1 + 2 * ( 1 - 1 ) + J
0030               PRES ( IE ) = PRE
0031            21 CONTINUE
              C
0032            30 CONTINUE
0033            40 CONTINUE
              C
              C    IF ( IWDD9 .EQ. 0 ) RETURN
              C
              C
0034           112 FORMAT(I5)
0035           113 FORMAT(I5,2F10.0)
              C
0036           212 FORMAT(1H ,I5)
0037           213 FORMAT(1H ,I5,2F10.5)
              C
0038           304 FORMAT(1H ,20H********************,/,
                1        1H ,20H* S E T   N O.   4 *,/,
                2        1H ,20H********************,/)
              C
0039               RETURN
0040               END
```

```
FORTRAN IV G1  RELEASE 2.0           PRESS            DATE = 84327          01/49/16              PAGE 0003

   *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
   *OPTIONS IN EFFECT*  NAME = PRESS    , LINECNT =       60
   *STATISTICS*    SOURCE STATEMENTS =        40,PROGRAM SIZE =      1280
   *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
 0001                   SUBROUTINE SAPW ( X,Y,Z,INOD,HH,ID,
                       1              PRES,
                       2              NPOIN,NELEM,NCOLN,IHED )
                  C
 0002                   IMPLICIT REAL*8 (A-H,O-Z)
                  C
                  C
 0003                   COMMON /GT1/ A ( 1 )
                  C
 0004                   DIMENSION X(NPOIN),Y(NPOIN),Z(NPOIN)
 0005                   DIMENSION INOD(4,NELEM),HH(NELEM)
 0006                   DIMENSION ID(NPOIN)
 0007                   DIMENSION PRES(NELEM)
                  C
                  C     DIMENSION ILOAD(2,NCOLN),ALOAD(6,NCOLN)
                  C
 0008                   DIMENSION IHED ( 12 )
                  C
 0009                   DIMENSION IDD(6,5)
                  C
 0010                   DATA IDD/6*0,5*0,1,4*0,1,0,3*0,1,2*0,6*1/
                  C
                  C**************************************************
                  C
 0011                   REWIND 99
                  C
                  C**************************************************
                  C
                  C     SECTION I
                  C     HEADING CARD
                  C
                  C**************************************************
                  C
 0012                   WRITE ( 99 , 101 ) ( IHED ( I ) , I = 1 , 12 )
                  C
                  C**************************************************
                  C
                  C     SECTION II
                  C     MASTER CONTROL CARD
                  C
                  C**************************************************
                  C
 0013                   NUMNP  = NPOIN
 0014                   NELTYP = 1
 0015                   LL     = NCOLN
 0016                   NF     = 0
 0017                   NDYN   = 0
 0018                   MODEX  = 0
 0019                   NAD    = 0
 0020                   KEQB   = 0
                  C
 0021                   WRITE ( 99 , 201 ) NUMNP,NELTYP,LL,NF,NDYN,MODEX,NAD,KEQB
                  C
                  C**************************************************
                  C
                  C     SECTION III
                  C     NODAL POINT DATA
                  C
```

```
FORTRAN IV G1  RELEASE 2.0           SAPW              DATE = 84327          01/49/16              PAGE 0002
                 C*********************************************
                 C
 0022                  CT =  0
 0023                  CTT = 0
 0024                  KN = 0
 0025                  TN = 0.
                 C
 0026                  DO 1 N = 1 , NPOIN
 0027                  I1 = ID ( N )
                 C
 0028                  WRITE ( 99 , 301 ) CT,N,CTT,(IDD(J,I1),J=1,6),
                     * X(N),Y(N),Z(N),KN,TN
                 C
 0029                1 CONTINUE
                 C
                 C*********************************************
                 C
                 C     SECTION IV
                 C     ELEMENT DATA
                 C
                 C*********************************************
                 C
                 C     A. CONTROL CARD
                 C
                 C*********************************************
                 C
 0030                  I1 = 6
 0031                  I2 = NELEM
 0032                  I3 = 1
                 C
 0033                  WRITE ( 99 , 401 ) I1,I2,I3
                 C
                 C*********************************************
                 C
                 C     SECTION IV
                 C     ELEMENT DATA
                 C
                 C*********************************************
                 C
                 C     B. MATERIAL PROPERTY INFORMATION
                 C
                 C*********************************************
                 C
 0034                  I1  = 1
 0035                  MD  = 0.
 0036                  TEX = 0.
 0037                  TEY = 0.
 0038                  TXY = 0.
                 C
 0039                  WRITE ( 99 , 402 ) I1,MD,TEX,TEY,TXY
                 C
 0040                  CXX = 10.E6
 0041                  CXY = 2.E6
 0042                  CXS = 0.
 0043                  CYY = 10.E6
 0044                  CYS = 0.
 0045                  GXY = 4.E6
                 C
 0046                      WRITE ( 99 , 403 ) CXX,CXY,CXS,CYY,CYS,GXY
                     C
                     C***************************************************
                     C
                     C     SECTION IV
                     C     ELEMENT DATA
                     C
                     C***************************************************
                     C
                     C     C. ELEMENT LOAD MULTIPLIERS
                     C
                     C***************************************************
                     C
                     C     PRESSURE
                     C
 0047                      PA = 1.
 0048                      PB = 0.
 0049                      PC = 0.
 0050                      PD = 0.
                     C
 0051                      WRITE  ( 99 , 404 ) PA,PB,PC,PD
                     C
                     C     THERMAL
                     C
 0052                      PA = 0.
 0053                      PB = 0.
 0054                      PC = 0.
 0055                      PD = 0.
                     C
 0056                      WRITE  ( 99 , 404 ) PA,PB,PC,PD
                     C
                     C     X-GRAVITY
                     C
 0057                      PA = 0.
 0058                      PB = 0.
 0059                      PC = 0.
 0060                      PD = 0.
                     C
 0061                      WRITE  ( 99 , 404 ) PA,PB,PC,PD
                     C
                     C     Y-GRAVITY
                     C
 0062                      PA = 0.
 0063                      PB = 0.
 0064                      PC = 0.
 0065                      PD = 0.
                     C
 0066                      WRITE  ( 99 , 404 ) PA,PB,PC,PD
                     C
                     C     Z-GRAVITY
                     C
 0067                      PA = 0.
 0068                      PB = 0.
 0069                      PC = 0.
 0070                      PD = 0.
                     C
 0071                      WRITE  ( 99 , 404 ) PA,PB,PC,PD
                     C
```

```
                  C**********************************************
                  C
                  C     SECTION IV
                  C     ELEMENT DATA
                  C
                  C**********************************************
                  C
                  C     D. ELEMENT CARDS
                  C
                  C**********************************************
                  C
0072                    NO  = 0
0073                    MID = 1
0074                    KN  = 0
0075                    MTV = 0.
0076                    MTG = 0.
                  C
0077                    DO 2 N = 1 , NELEM
                  C
0078                    WRITE ( 99 , 405 ) N,(INOD(J,N),J=1,4),
                       1                   NO,MID,KN,HH(N),
                       2                   PRES(N),MTV,MTG
                  C
0079                  2 CONTINUE
                  C
                  C**********************************************
                  C
                  C     SECTION V
                  C     CONCENTRATED LOAD/MASS DATA
                  C
                  C**********************************************
                  C
                  C     DO 3 J = 1 , NCOLN
                  C
                  C     N   = ILOAD ( 1 , J )
                  C     L   = ILOAD ( 2 , J )
                  C     FX  = ALOAD ( 1 , J )
                  C     FY  = ALOAD ( 2 , J )
                  C     FZ  = ALOAD ( 3 , J )
                  C     AMX = ALOAD ( 4 , J )
                  C     AMY = ALOAD ( 5 , J )
                  C     AMZ = ALOAD ( 6 , J )
                  C
                  C     WRITE ( 99 , 501 ) N,L,FX,FY,FZ,AMX,AMY,AMZ
                  C
                  C   3 CONTINUE
0080                    N  = 0
0081                    L  = 0
0082                    FX = 0.
0083                    FY = 0.
0084                    FZ = 0.
0085                    AM = 0.
                  C
0086                    WRITE ( 99 , 501 ) N,L,FX,FY,FZ,AM,AM,AM
                  C
                  C**********************************************
                  C
                  C     SECTION VI
                  C      ELEMENT LOAD MULTIPLIERS
                  C
                  C********************************************
                  C
   0087                  DO 4 I = 1 , NCOLN
   0088                  EM1 = 1.
   0089                  EM2 = 0.
   0090                  EM3 = 0.
   0091                  EM4 = 0.
                  C
   0092                  WRITE ( 99 , 601 ) EM1,EM2,EM3,EM4
                  C
   0093                4 CONTINUE
                  C
   0094                  REWIND 99
                  C
   0095              101 FORMAT(12A4)
                  C
   0096              201 FORMAT(18I5)
                  C
   0097              301 FORMAT(2(A1,I4),5I5,3F10.5,I5,F10.2)
                  C
   0098              401 FORMAT(3I5)
   0099              402 FORMAT(I10,20X,4F10.2)
   0100              403 FORMAT(6F10.1)
   0101              404 FORMAT(4F10.5)
   0102              405 FORMAT(8I5,4F10.5)
                  C
   0103              501 FORMAT(2I5,6F10.4)
                  C
   0104              601 FORMAT(4F10.5)
                  C
   0105                  RETURN
   0106                  END
```

```
FORTRAN IV G1  RELEASE 2.0           SAPW              DATE = 84327          01/49/16            PAGE 0006

  *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
  *OPTIONS IN EFFECT*  NAME = SAPW    , LINECNT =       60
  *STATISTICS*    SOURCE STATEMENTS =       106,PROGRAM SIZE =      2820
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G1  RELEASE 2.0          INPTW1          DATE = 84327          01/49/16          PAGE 0001

  0001                   SUBROUTINE INPTW1 ( BR,ITHW,ITHWF,ITHD,THICK,ITHR,
                        1                    NR1, NITHW,NWF,NR2,NTHIC,NRING,
                        2                    NXF,NZF,THIS,THOS,THFP,THFPI,
                        3                    ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN,
                        4                    NWEB,NWEBF,NWFS,NPRG,NERG,NPOIN,NELEM,
                        5                    IHEDD,IW )
                   C
  0002                   IMPLICIT REAL*8 (A-H,O-Z)
                   C
  0003                   COMMON /GT1/ A ( 1 )
                   C
  0004                   DIMENSION BR(NR1)
  0005                   DIMENSION ITHW(3,NITHW),ITHWF(NWF)
  0006                   DIMENSION ITHD(NR2),THICK(NTHIC)
  0007                   DIMENSION ITHR(NRING)
                   C
  0008                   DIMENSION IHEDD ( 12 )
                   C
  0009                   WRITE ( IW , 301 )
                   C
  0010                   WRITE ( IW , 200 ) ( IHEDD ( I ) , I = 1 , 12 )
  0011                   WRITE ( IW , 201 ) NRING,NTHIC,NITHW,NWF,NXF,NZF
  0012                   WRITE ( IW , 202 ) ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN
  0013                   WRITE ( IW , 401 )
                   C
  0014                   WRITE ( IW , 302 )
                   C
  0015                   WRITE ( IW , 203 ) ( BR ( I ) , I = 1 , NR1 )
  0016                   WRITE ( IW , 401 )
                   C
  0017                   WRITE ( IW , 303 )
                   C
  0018                   WRITE ( IW , 204 ) THIS , THOS , THFP , THFPI
                   C
  0019                   WRITE ( IW , 205 ) ( ITHR  ( I ) , I = 1 , NRING )
                   C
  0020                   WRITE ( IW , 206 ) ( ITHW ( 1 , J ) , J = 1 , NITHW )
  0021                   WRITE ( IW , 207 ) ( ITHW ( 2 , J ) , J = 1 , NITHW )
  0022                   WRITE ( IW , 208 ) ( ITHW ( 3 , J ) , J = 1 , NITHW )
                   C
  0023                   WRITE ( IW , 209 ) ( ITHWF ( I ) , I = 1 , NWF   )
                   C
  0024                   WRITE ( IW , 210 ) ( ITHD  ( I ) , I = 1 , NR2   )
                   C
  0025                   WRITE ( IW , 211 ) ( THICK ( I ) , I = 1 , NTHIC )
  0026                   WRITE ( IW , 401 )
                   C
                   C
  0027               200 FORMAT(1H ,12A6)
  0028               201 FORMAT(1H ,6I5)
  0029               202 FORMAT(1H ,6F10.5,/,1H )
  0030               203 FORMAT(1H ,10F10.4,/,1H )
  0031               204 FORMAT(1H ,4F10.5)
  0032               205 FORMAT(1H ,26I5)
  0033               206 FORMAT(1H ,26I5)
  0034               207 FORMAT(1H ,26I5)
  0035               208 FORMAT(1H ,26I5)
  0036               209 FORMAT(1H ,26I5)
```

```
FORTRAN IV G1  RELEASE 2.0            INPTW1            DATE = 84327          01/49/16             PAGE 0002

 0037                210 FORMAT(1H ,26I5)
 0038                211 FORMAT(1H ,13F10.5,/,1H )
                   C
 0039                301 FORMAT(1H ,20H********************,/,
                        1        1H ,20H* S E T   N O.   1 *,/,
                        2        1H ,20H********************,/)
                   C
 0040                302 FORMAT(1H ,20H********************,/,
                        1        1H ,20H* S E T   N O.   2 *,/,
                        2        1H ,20H********************,/)
                   C
 0041                303 FORMAT(1H ,20H********************,/,
                        1        1H ,20H* S E T   N O.   3 *,/,
                        2        1H ,20H********************,/)
                   C
 0042                401 FORMAT(1H ,/)
                   C
 0043                    RETURN
 0044                    END
```

```
FORTRAN IV G1  RELEASE 2.0           INPTW1           DATE = 84327        01/49/16             PAGE 0003

     *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
     *OPTIONS IN EFFECT*  NAME = INPTW1  , LINECNT =       60
     *STATISTICS*    SOURCE STATEMENTS =        44,PROGRAM SIZE =      2544
     *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G1  RELEASE 2.0             INPTW2             DATE = 84327          01/49/16                PAGE 0001

 0001                   SUBROUTINE INPTW2 ( BR,ITHW,ITHWF,ITHD,THICK,ITHR,
                       1                    PRES,
                       2                    NR1, NITHW,NWF,NR2,NTHIC,NRING,
                       3                    NXF,NZF,THIS,THOS,THFP,THFPI,
                       4                    ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN,
                       5                    NWEB,NWEBF,NWFS,NPRG,NERG,NPOIN,NELEM,
                       6                    IHEDD,IW )
                 C
 0002                   IMPLICIT REAL*8 (A-H,O-Z)
                 C
 0003                   COMMON /GT1/ A ( 1 )
                 C
 0004                   DIMENSION BR(NR1)
 0005                   DIMENSION ITHW(3,NITHW),ITHWF(NWF)
 0006                   DIMENSION ITHD(NR2),THICK(NTHIC)
 0007                   DIMENSION ITHR(NRING)
 0008                   DIMENSION PRES(NELEM)
                 C
 0009                   DIMENSION IHEDD ( 12 )
                 C
 0010                   WRITE ( IW , 200 ) ( IHEDD ( I ) , I = 1 , 12 )
 0011                   WRITE ( IW , 201 ) NRING,NTHIC,NITHW,NWF,NXF,NZF
 0012                   WRITE ( IW , 202 ) ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN
                 C
 0013                   WRITE ( IW , 203 ) ( BR ( I ) , I = 1 , NR1 )
 0014                   WRITE ( IW , 401 )
                 C
                 C
 0015                   WRITE ( IW , 204 ) THIS , THOS , THFP , THFPI
 0016                   WRITE ( IW , 401 )
                 C
 0017                   WRITE ( IW , 205 ) ( ITHR  ( I ) , I = 1 , NRING )
 0018                   WRITE ( IW , 401 )
                 C
 0019                   WRITE ( IW , 206 ) ( ITHW ( 1 , J ) , J = 1 , NITHW )
 0020                   WRITE ( IW , 401 )
 0021                   WRITE ( IW , 207 ) ( ITHW ( 2 , J ) , J = 1 , NITHW )
 0022                   WRITE ( IW , 401 )
 0023                   WRITE ( IW , 208 ) ( ITHW ( 3 , J ) , J = 1 , NITHW )
 0024                   WRITE ( IW , 401 )
                 C
 0025                   WRITE ( IW , 209 ) ( ITHWF ( I ) , I = 1 , NWF   )
 0026                   WRITE ( IW , 401 )
                 C
 0027                   WRITE ( IW , 210 ) ( ITHD  ( I ) , I = 1 , NR2   )
 0028                   WRITE ( IW , 401 )
                 C
 0029                   WRITE ( IW , 211 ) ( THICK ( I ) , I = 1 , NTHIC )
 0030                   WRITE ( IW , 401 )
                 C
                 C*************************************************************
                 C
 0031                   WRITE ( IW , 212 ) NWEB,NWEBF,NWFS,NPRG,NERG,NPOIN,NELEM
 0032                   WRITE ( IW , 401 )
                 C
                 C*************************************************************
 0033                   WRITE ( IW , 301 )
 0034                   WRITE ( IW , 302 )
```

```
                  C
  0035                 DO 90 I = 1 , NELEM
  0036                 IF ( PRES ( I ) .NE. 0.0 )
                     1      WRITE ( IW , 101 ) I,PRES(I)
  0037              90 CONTINUE
                  C
  0038             101 FORMAT(1H ,I5,F10.5)
                  C
  0039             200 FORMAT(1H1,12A6)
                  C
  0040             201 FORMAT(
                     1    1H ,46H TOTAL NO. OF RINGES                            = ,I5,/,
                     2    1H ,46H TOTAL NO. OF DIFF. THICKNESSES                 = ,I5,/,
                     3    1H ,46H TOTAL NO. OF GROUP THICKNESSES                 = ,I5,/,
                     4    1H ,46H TOTAL NO. OF WEBS          IN FOUNDATION       = ,I5,/,
                     5    1H ,46H TOTAL NO. OF X DIVISIONS IN FOUNDATION         = ,I5,/,
                     6    1H ,46H TOTAL NO. OF Z DIVISIONS IN FOUNDATION         = ,I5,/)
                  C
  0041             202 FORMAT(
                     1    1H ,46H ANGLE BETWEEN WEBS                             = ,F10.5,/,
                     2    1H ,46H INNER RADIUS                                   = ,F10.5,/,
                     3    1H ,46H DEPTH OF ANY RING                              = ,F10.5,/,
                     4    1H ,46H ANGLE BETWEEN GLOBAL Z AND FOUNDATION EDGE = ,F10.5,/,
                     5    1H ,46H EXTESION OF FOUNDATION IN GLOBAL X             = ,F10.5,/,
                     6    1H ,46H EXTESION OF FOUNDATION IN GLOBAL Z             = ,F10.5,/)
                  C
  0042             203 FORMAT(1H ,29H DISTANCE BETWEEN RINGES ARE ,/,10F10.4,/,1H )
                  C
  0043             204 FORMAT(
                     1    1H ,46H THICKNESS OF INNER SHELL                       = ,F10.5,/,
                     2    1H ,46H THICKNESS OF OUTER SHELL                       = ,F10.5,/,
                     3    1H ,46H THICKNESS OF FOUNDATION PLATE ( OUTER )        = ,F10.5,/,
                     4    1H ,46H THICKNESS OF FOUNDATION PLATE ( INNER )        = ,F10.5,/)
  0044             205 FORMAT(
                     1    1H ,46H INDEX OF THICKNESS OF RINGES                   = ,/,
                     2    1H ,26I5,//,1H )
  0045             206 FORMAT(
                     1    1H ,46H INDEX FROM WEB NO. (  THICKNESS )              = ,/,
                     2    1H ,26I5,//,1H )
  0046             207 FORMAT(
                     1    1H ,46H INDEX TO   WEB NO. (  THICKNESS )              = ,/,
                     2    1H ,26I5,//,1H )
  0047             208 FORMAT(
                     1    1H ,46H INDEX OF THICKNESS TYPE OR WEBS                = ,/,
                     2    1H ,26I5,//,1H )
  0048             209 FORMAT(
                     1    1H ,46H INDEX OF THICKNESS TYPE OF FOUN. WEBS          = ,/,
                     2    1H ,26I5,//,1H )
  0049             210 FORMAT(
                     1    1H ,46H INDEX OF THICKNESS TYPE OF FOUN. DIAG.         = ,/,
                     2    1H ,26I5,//,1H )
  0050             211 FORMAT(
                     1    1H ,46H DIFF. THICKNESSES                              = ,/,
                     2    1H ,13F10.5,//,1H )
                  C
  0051             212 FORMAT(
                     1    1H ,46H TOTAL NO. OF WEBS IN ANY RING                  = ,I5,/,
                     2    1H ,46H TOTAL NO. OF WEBS IN FOUNDATION                = ,I5,/,
                   3    1H ,46H WEB NO. WHERE FOUNDATION EDGE STRART         = ,I5,/,
                   4    1H ,46H TOTAL NO. OF NODES IN RINGS                  = ,I5,/,
                   5    1H ,46H TOTAL NO. OF ELEMENTS IN RINGS               = ,I5,/,
                   6    1H ,46H TOTAL NO. OF NODES IN STRCTURE               = ,I5,/,
                   7    1H ,46H TOTAL NO. OF ELEMENTS IN STRCTURE            = ,I5,/)
              C
0052            301 FORMAT(1H ,22HPRES. LOADINGS         ,/)
0053            302 FORMAT(1H ,22HEL.   LOADINGS         ,/)
              C
0054            401 FORMAT(1H ,/)
              C
0055                RETURN
0056                END
```

```
FORTRAN IV G1  RELEASE 2.0              INPTW2              DATE = 84327          01/49/16                PAGE 0004

   *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
   *OPTIONS IN EFFECT*  NAME = INPTW2  , LINECNT =       60
   *STATISTICS*    SOURCE STATEMENTS =        56,PROGRAM SIZE =      4372
   *STATISTICS*  NO DIAGNOSTICS GENERATED

   *STATISTICS*  NO DIAGNOSTICS THIS STEP
```

```
H96-LEVEL LINKAGE EDITOR OPTIONS SPECIFIED XREF,LET,LIST,MAP
          DEFAULT OPTION(S) USED -  SIZE=(262144,49152)

                                                CROSS REFERENCE TABLE

 CONTROL SECTION                        ENTRY

   NAME      ORIGIN  LENGTH               NAME     LOCATION     NAME    LOCATION     NAME    LOCATION     NAME    LOCATION
 MAIN            00     3F8
 SUB1           3F8    11A8
 RED2          15A0     7C8
 RED3          1D68     56C
 WEB1          22D8     518
 COR1          27F0     668
 COR2          2E58    1080
 TOP1          3F08     8B8
 TOP2          47C0     F64
 THIH          5728     F04
 IDVL          6630     E8C
 PRESS         74C0     500
 SAPW          79C0     B04
 INPTW1        84C8     9F0
 INPTW2        8EB8    1114
 IHOSATN2*     9FD0     1E8

 IHOLSCN *     A1B8     290              ATAN2      9FD0     IH$ATAN2    9FD0     ATAN       9FE4     IH$ATAN    9FE4
                                         DCOS       A1B8     IH$DCOS     A1B8     DSIN       A1DC     IH$DSIN    A1DC
 IHOECOMH*     A448     EB0
                                         IBCOM#     A474     IB081971    A474     FDIOCS#    A530     INTSWTCH   B230
 FIOAP#  *     B2F8     6F4
                                         AP081971   B76C
 IHOCOMH2*     B9F0     9C5
                                         SEQDASD    BDAA
 IHOFCVTH*     C3B8     A43
                                         ADCON#     C3B8     FCVAOUTP    C462     FCVLOUTP   C4F2     FCVZOUTP   C64E
                                         FCVIOUTP   CA28     FCVEOUTP    CB1A     FCVCOUTP   CB1A     INT6SWCH   CD7C
 IHOEFNTH*     CE00     800
                                         ARITH#     CE00     ADJSWTCH    D394
 IHOEFIOS*     D600    118C
                                         FIOCS#     D600     FIOCSBEP    D606
 IHOFIOS2*     E790     642
 IHOERRM *     EDD8     624
                                         ERRMON     EDD8     IHOERRE     EDF0
 IHOUOPT *     F400     3B8
 IHOFCONI*     F7B8     2FD
                                         FQCONI#    F7B8
 IHOFCONO*     FAB8     4C2
                                         FQCONO#    FAB8
 IHOETRCH*     FF80     2AE
                                         IHOTRCH    FF80     ERRTRA      FF88
 IHOUATBL*    10230     638
 IHOFTEN *    10868     198
```

```
NAME   ORIGIN  LENGTH              NAME    LOCATION    NAME   LOCATION    NAME   LOCATION    NAME   LOCATION
GT1     10A00   27100              FTEN#     10868

LOCATION  REFERS TO SYMBOL  IN CONTROL SECTION          LOCATION  REFERS TO SYMBOL  IN CONTROL SECTION
      78            GT1               GT1                      9C            IBCOM#            IHOECOMH
      A0            SUB1              SUB1                    470            GT1               GT1
     4A8            RED2              RED2                    4AC            RED3              RED3
     4B0            WEB1              WEB1                    4B4            COR1              COR1
     4B8            COR2              COR2                    4BC            TOP1              TOP1
     4C0            TOP2              TOP2                    4C4            THIH              THIH
     4C8            IDVL              IDVL                    4CC            INPTW1            INPTW1
     4D0            PRESS             PRESS                   4D4            INPTW2            INPTW2
     4D8            SAPW              SAPW                    4DC            IBCOM#            IHOECOMH
    1618            GT1               GT1                    1658            IBCOM#            IHOECOMH
    165C            ATAN              IHOSATN2               1660            DCOS              IHOLSCN
    1DE0            GT1               GT1                    1E18            IBCOM#            IHOECOMH
    2350            GT1               GT1                    2398            IBCOM#            IHOECOMH
    2868            GT1               GT1                    28A0            IBCOM#            IHOECOMH
    28A4            ATAN              IHOSATN2               28A8            DSIN              IHOLSCN
    28AC            DCOS              IHOLSCN                2ED0            GT1               GT1
    2F8C            IBCOM#            IHOECOMH               3F80            GT1               GT1
    3FC4            IBCOM#            IHOECOMH               4838            GT1               GT1
    48C4            IBCOM#            IHOECOMH               57A0            GT1               GT1
    5838            IBCOM#            IHOECOMH               66A8            GT1               GT1
    6744            IBCOM#            IHOECOMH               7538            GT1               GT1
    7580            IBCOM#            IHOECOMH               7A38            GT1               GT1
    7A6C            IBCOM#            IHOECOMH               8540            GT1               GT1
    8580            IBCOM#            IHOECOMH               8F30            GT1               GT1
    8F78            IBCOM#            IHOECOMH               A120            IBCOM#            IHOECOMH
    A16C            IHOERRM           IHOERRM                A3C4            IBCOM#            IHOECOMH
    A3C8            IHOERRM           IHOERRM                A530            SEQDASD           IHOCOMH2
    A588            IHOCOMH2          IHOCOMH2               B134            ADCON#            IHOFCVTH
    B12C            FIOCS#            IHOEFIOS               B138            ARITH#            IHOEFNTH
    B154            ADJSWTCH          IHOEFNTH               B108            IHOUOPT           IHOUOPT
    B24C            IHOCMSE          $UNRESOLVED(W)          B13C            FCVEOUTP          IHOFCVTH
    B140            FCVLOUTP          IHOFCVTH               B144            FCVIOUTP          IHOFCVTH
    B148            FCVCOUTP          IHOFCVTH               B14C            FCVAOUTP          IHOFCVTH
    B150            FCVZOUTP          IHOFCVTH               B234            IHOASYNC         $UNRESOLVED(W)
    B08C            IHOERRM           IHOERRM                B0E0            IHOERRE           IHOERRM
    B110            IHOCOMH2          IHOCOMH2               B28C            FIOAP#            FIOAP#
    B2F0            FIOAP#            FIOAP#                 B2F4            FIOAP#            FIOAP#
    B0E4            IHOCOMH2          IHOCOMH2               B0E8            IHOCOMH2          IHOCOMH2
    B0EC            IHOCOMH2          IHOCOMH2               B0F0            IHOCOMH2          IHOCOMH2
    B784            IBCOM#            IHOECOMH               B81C            IHOCOMH2          IHOCOMH2
    BB5D            IHOECOMH          IHOECOMH               BC28            IHOECOMH          IHOECOMH
    C215            IHOECOMH          IHOECOMH               C225            IHOECOMH          IHOECOMH
    C235            IHOECOMH          IHOECOMH               CBE0            IBCOM#            IHOECOMH
    CBDC            IHOERRM           IHOERRM                CC30            FQCONO#           IHOFCONO
    CC34            FQCONI#           IHOFCONI               D3F4            IBCOM#            IHOECOMH
```

```
 LOCATION  REFERS TO SYMBOL  IN CONTROL SECTION            LOCATION  REFERS TO SYMBOL  IN CONTROL SECTION
    D3F8             INTSWTCH         IHOECOMH                    D390            INT6SWCH         IHOFCVTH
    D38C             IHOUOPT          IHOUOPT                     D400            ADCON#           IHOFCVTH
    D3FC             FIOCS#           IHOEFIOS                    D500            IHOERRM          IHOERRM
    D76C             IHOASYNC        $UNRESOLVED(W)               D770            IHOCMSE         $UNRESOLVED(W)
    D764             IHOERRM          IHOERRM                     D768            IHOFIOS2         IHOFIOS2
    E51C             IHOUATBL         IHOUATBL                    E528            IBCOM#           IHOECOMH
    E53D             IHOFIOS2         IHOFIOS2                    E554            IHOFIOS2         IHOFIOS2
    E785             IHOFIOS2         IHOFIOS2                    F3EC            IHOUOPT          IHOUOPT
    F3F0             IBCOM#           IHOECOMH                    F3F4            IHOTRCH          IHOETRCH
    F3F8             FIOCSBEP         IHOEFIOS                    FA4C            IHOQCONI        $UNRESOLVED(W)
    FA48             FQTEN#          $UNRESOLVED(W)               FA44            FTEN#            IHOFTEN
    FEC4             IHOQCONO        $UNRESOLVED(W)               FEC0            FQTEN#          $UNRESOLVED(W)
    FEBC             FTEN#            IHOFTEN                    10118            LDFIO#          $UNRESOLVED(W)
   10110             IBCOM#           IHOECOMH                   10114            ADCON#           IHOFCVTH
   1011C             FIOCSBEP         IHOEFIOS
 ENTRY ADDRESS       00

 TOTAL LENGTH      37B00
****NOZZLE    NOW REPLACED IN DATA SET    AMODE 24
RMODE IS 24
AUTHORIZATION CODE IS          0.
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           UU        UU  BBBBBBBBBBBB  SSSSSSSSSSSS  CCCCCCCCCCCC  MMM      MMM  WW        WW  SSSSSSSSSSSS  GGGGGGGGGGGG
           UU        UU  BB        BB  SS        SS  CC        CC  MMMM    MMMM  WW        WW  SS        SS  GG        GG
           UU        UU  BB        BB  SS            CC            MM MM  MM MM  WW        WW  SS            GG
           UU        UU  BB       BB   SSS           CC            MM  MMMM  MM  WW        WW  SSS           GG
           UU        UU  BBBBBBBBBB     SSSSSSSSS    CC            MM   MM   MM  WW        WW   SSSSSSSSS    GG
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           UU        UU  BB        BB  SS        SS  CC        CC  MM        MM  WWWW    WWWW  SS        SS  GG        GG
           UUUUUUUUUUUU  BBBBBBBBBBBB  SSSSSSSSSSSS  CCCCCCCCCCCC  MM        MM  WWW      WWW  SSSSSSSSSSSS  GGGGGGGGGGGG
            UUUUUUUUUU   BBBBBBBBBBB    SSSSSSSSSS     CCCCCCCCCC   MM        MM  WW        WW   SSSSSSSSSS     GGGGGGGGGG

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                        JJ      33        33  77      77    88        88  33        33                GG        GG
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                        JJ                33        77       88      88             33                GG
                        JJ             3333       77         88888888           3333                 GG
                        JJ             3333       77         88888888           3333                 GG     GGGGG
                        JJ                33       77        88      88             33                GG     GGGGG
                  JJ    JJ                33       77       88        88            33                GG        GG
                  JJ    JJ      33        33       77       88        88  33        33                GG        GG
                  JJJJJJJJ      333333333333       77       888888888888  333333333333                GGGGGGGGGGGG
                   JJJJJJ        3333333333        77        8888888888    3333333333                  GGGGGGGGGG

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                                GGGGGGGGGGGG  AAAAAAAAAAAA  MMM      MMM   IIIIIIIIII   LL
                                GG        GG  AA        AA  MMMM    MMMM       II       LL
                                GG            AA        AA  MM MM  MM MM       II       LL
                                GG            AA        AA  MM  MMMM  MM       II       LL
                                GG            AAAAAAAAAAAA  MM   MM   MM       II       LL
                                GG     GGGGG  AAAAAAAAAAAA  MM        MM       II       LL
                                GG     GGGGG  AA        AA  MM        MM       II       LL
                                GG        GG  AA        AA  MM        MM       II       LL
                                GG        GG  AA        AA  MM        MM       II       LL
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                                 GGGGGGGGGG   AA        AA  MM        MM   IIIIIIIIII   LLLLLLLLLLLL
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4        GAMIL                ROOM        3.58.00 PM 22 NOV 84  PRINTER4  SYS C6DP  END   G*
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UU        UU  BB        BB  SS        SS  CC        CC  MMMM    MMMM  WW        WW  SS        SS  GG        GG
UU        UU  BB        BB  SS            CC            MM MM  MM MM  WW        WW  SS            GG
UU        UU  BB       BB   SSS           CC            MM  MMMM  MM  WW        WW  SSS           GG
UU        UU  BBBBBBBBBB     SSSSSSSSS    CC            MM   MM   MM  WW        WW   SSSSSSSSS    GG
UU        UU  BBBBBBBBBB      SSSSSSSSS   CC            MM        MM  WW   WW   WW    SSSSSSSSS   GG     GGGGG
UU        UU  BB       BB            SSS  CC            MM        MM  WW  WWWW  WW           SSS  GG     GGGGG
UU        UU  BB        BB            SS  CC            MM        MM  WW WW  WW WW            SS  GG        GG
UU        UU  BB        BB  SS        SS  CC        CC  MM        MM  WWWW    WWWW  SS        SS  GG        GG
UUUUUUUUUUUU  BBBBBBBBBBBB  SSSSSSSSSSSS  CCCCCCCCCCCC  MM        MM  WWW      WWW  SSSSSSSSSSSS  GGGGGGGGGGGG
 UUUUUUUUUU   BBBBBBBBBBB    SSSSSSSSSS    CCCCCCCCCC   MM        MM  WW        WW   SSSSSSSSSS    GGGGGGGGGG

         JJJJJJJJJ   3333333333   777777777777   8888888888    3333333333                  GGGGGGGGGG
         JJJJJJJJJ  333333333333  77777777777   888888888888  333333333333                GGGGGGGGGGGG
              JJ    33        33  77       77   88        88  33        33                GG        GG
              JJ              33          77    88        88            33                GG
              JJ              33         77      88      88             33                GG
              JJ          3333          77        88888888          3333                  GG
              JJ          3333          77        88888888          3333                  GG     GGGGG
              JJ              33        77       88      88             33                GG     GGGGG
      JJ      JJ              33        77      88        88            33                GG        GG
      JJ      JJ    33        33        77      88        88  33        33                GG        GG
       JJJJJJJJ     333333333333        77      888888888888  333333333333                GGGGGGGGGGGG
        JJJJJJ       3333333333         77       8888888888    3333333333                  GGGGGGGGGG

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                    GGGGGGGGGGGG  AAAAAAAAAAAA  MMM      MMM  IIIIIIIIII    LL
                    GG        GG  AA        AA  MMMM    MMMM      II        LL
                    GG            AA        AA  MM MM  MM MM      II        LL
                    GG            AA        AA  MM  MMMM  MM      II        LL
                    GG            AAAAAAAAAAAA  MM   MM   MM      II        LL
                    GG     GGGGG  AAAAAAAAAAAA  MM        MM      II        LL
                    GG     GGGGG  AA        AA  MM        MM      II        LL
                    GG        GG  AA        AA  MM        MM      II        LL
                    GG        GG  AA        AA  MM        MM      II        LL
                    GGGGGGGGGGGG  AA        AA  MM        MM  IIIIIIIIII    LLLLLLLLLLL
                     GGGGGGGGGG   AA        AA  MM        MM  IIIIIIIIII    LLLLLLLLLLL

*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
*G  END  JOB 3783 UBSCMWSG 0002 0001 GCS4     GAMIL                ROOM      3.58.01 PM 22 NOV 84  PRINTER4  SYS C6DP  END  G*
************************************************************************************************************************************
************************************************************************************************************************************
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```
UU        UU  BBBBBBBBBBB    SSSSSSSSSS    CCCCCCCCCC   MM        MM  WW        WW   SSSSSSSSSS    GGGGGGGGGG
UU        UU  BBBBBBBBBBBB  SSSSSSSSSSSS  CCCCCCCCCCCC  MMM      MMM  WW        WW  SSSSSSSSSSSS  GGGGGGGGGGGG
UU        UU  BB        BB  SS        SS  CC        CC  MMMM    MMMM  WW        WW  SS        SS  GG        GG
UU        UU  BB        BB  SS            CC            MM MM  MM MM  WW        WW  SS            GG
UU        UU  BB       BB   SSS           CC            MM  MMMM  MM  WW        WW  SSS           GG
UU        UU  BBBBBBBBBB     SSSSSSSSS    CC            MM   MM   MM  WW        WW   SSSSSSSSS    GG
UU        UU  BBBBBBBBBB      SSSSSSSSS   CC            MM        MM  WW   WW   WW    SSSSSSSSS   GG     GGGGG
UU        UU  BB       BB            SSS  CC            MM        MM  WW  WWWW  WW           SSS  GG     GGGGG
UU        UU  BB        BB            SS  CC            MM        MM  WW WW  WW WW            SS  GG        GG
UU        UU  BB        BB  SS        SS  CC        CC  MM        MM  WWWW    WWWW  SS        SS  GG        GG
UUUUUUUUUUUU  BBBBBBBBBBBB  SSSSSSSSSSSS  CCCCCCCCCCCC  MM        MM  WWW      WWW  SSSSSSSSSSSS  GGGGGGGGGGGG
 UUUUUUUUUU   BBBBBBBBBBB    SSSSSSSSSS    CCCCCCCCCC   MM        MM  WW        WW   SSSSSSSSSS    GGGGGGGGGG

  JJJJJJJJJJ   3333333333   777777777777   8888888888    3333333333                  GGGGGGGGGG
  JJJJJJJJJJ  333333333333  77777777777   888888888888  333333333333                GGGGGGGGGGGG
      JJ      33        33  77      77    88        88  33        33                GG        GG
      JJ                33         77     88        88            33                GG
      JJ                33        77       88      88             33                GG
      JJ             3333        77         88888888           3333                 GG
      JJ             3333        77         88888888           3333                 GG     GGGGG
      JJ                33       77        88      88             33                GG     GGGGG
JJ    JJ                33       77       88        88            33                GG        GG
JJ    JJ      33        33       77       88        88  33        33                GG        GG
JJJJJJJJ      333333333333       77       888888888888  333333333333                GGGGGGGGGGGG
 JJJJJJ        3333333333        77        8888888888    3333333333                  GGGGGGGGGG

 GGGGGGGGGG    AAAAAAAAAA   MM        MM  IIIIIIIIII    LL
GGGGGGGGGGGG  AAAAAAAAAAAA  MMM      MMM  IIIIIIIIII    LL
GG        GG  AA        AA  MMMM    MMMM      II        LL
GG            AA        AA  MM MM  MM MM      II        LL
GG            AA        AA  MM  MMMM  MM      II        LL
GG            AAAAAAAAAAAA  MM   MM   MM      II        LL
GG     GGGGG  AAAAAAAAAAAA  MM        MM      II        LL
GG     GGGGG  AA        AA  MM        MM      II        LL
GG        GG  AA        AA  MM        MM      II        LL
GG        GG  AA        AA  MM        MM      II        LL
GGGGGGGGGGGG  AA        AA  MM        MM  IIIIIIIIII    LLLLLLLLLLLL
 GGGGGGGGGG   AA        AA  MM        MM  IIIIIIIIII    LLLLLLLLLLLL

*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
*G START JOB 3783 UBSCMWSG 0002 0001 GCS4          GAMIL               ROOM        3.57.33 PM 22 NOV 84  PRINTER4  SYS C6DP START  G*
```

```
                J E S 2   J O B   L O G  --  S Y S T E M   C 5 D P  --  N O D E   G C S 4

01.49.14 JOB 3783  IEF677I WARNING MESSAGE(S) FOR JOB UBSCMWSG ISSUED
01.49.14 JOB 3783  $HASP373 UBSCMWSG STARTED - INIT  5 - CLASS K - SYS C5DP
01.49.14 JOB 3783  IEF403I UBSCMWSG - STARTED - TIME=01.49.14
01.49.25 JOB 3783  IEF404I UBSCMWSG - ENDED - TIME=01.49.25
01.49.25 JOB 3783  $HASP395 UBSCMWSG ENDED

------ JES2 JOB STATISTICS ------

 22 NOV 84 JOB EXECUTION DATE

         7 CARDS READ

     2,170 SYSOUT PRINT RECORDS

         0 SYSOUT PUNCH RECORDS

      0.19 MINUTES EXECUTION TIME
 1    //UBSCMWSG JOB (9992835),'GAMIL',MSGLEVEL=1,
      //     TIME=1,CLASS=K,MSGCLASS=N,NOTIFY=UBSCMWS,                          JOB 3783
      //     PRTY=9
      ***ROUTE PRINT RMT7
 2    //STEP1 EXEC FTG1CL,SOURCE='BEDS.NOZZ.FORT',
      //            MEMBER=NOZZLE,LIBRARY='BEDS.NOZZ.LOAD'
 3    XXFTG1CL PROC SOUT='*',LOAD=LOAD,DECK=NODECK,MAP=NOMAP,MEMBER=GO,
      XX            XREF=XREF,LET=LET,LIST=LIST,LMAP=MAP,DISP=SHR,             00010000
      XX            USERLIB='SYS1.FORTGLIB'                                    00020000
 4    XXFORT   EXEC PGM=IGIFORT,REGION=704K,PARM='&LOAD,&DECK,&MAP'            00030000
 5    XXSTEPLIB  DD DSN=SYS1.FORTGLNK,DISP=SHR                                 00040000
 6    XXSYSPRINT DD SYSOUT=&SOUT                                               00050000
 7    XXSYSLIN   DD DSNAME=&LOADSET,UNIT=VIO,DISP=(MOD,PASS),                  00060000
      XX            SPACE=(80,(200,100),RLSE),DCB=BLKSIZE=80                   00070000
 8    XXSYSIN    DD DSN=&SOURCE(&MEMBER),DISP=SHR                              00080000
 9    XXLKED   EXEC PGM=IEWL,PARM='&XREF,&LET,&LIST,&LMAP',REGION=768K,        00090000
      XX            COND=(4,LT,FORT)                                           00100000
10    XXSYSLIB   DD DSN=&USERLIB,DISP=SHR                                      00110000
11    XX         DD DSNAME=SYS1.FORTGLIB,DISP=SHR                              00120000
12    XXSYSLMOD  DD DSNAME=&LIBRARY(&MEMBER),UNIT=SYSDA,DISP=(&DISP,PASS),     00130000
      XX            SPACE=(6144,(20,10,1),,,ROUND)                             00140000
13    XXSYSPRINT DD SYSOUT=&SOUT                                               00150001
14    XXSYSUT1   DD UNIT=VIO,SPACE=(1024,(100,10),RLSE),DCB=BLKSIZE=1024,      00160000
      XX            DSNAME=&SYSUT1                                             00170000
15    XXSYSLIN   DD DSNAME=&LOADSET,DISP=(OLD,DELETE)                          00180000
16    XX         DD DDNAME=SYSIN                                               00190000
                                                                               00200000
 STMT NO. MESSAGE
-
    4       IEF653I SUBSTITUTION JCL - PGM=IGIFORT,REGION=704K,PARM='LOAD,NODECK,NOMAP'
    6       IEF653I SUBSTITUTION JCL - SYSOUT=*
    8       IEF653I SUBSTITUTION JCL - DSN=BEDS.NOZZ.FORT(NOZZLE),DISP=SHR
    9       IEF653I SUBSTITUTION JCL - PGM=IEWL,PARM='XREF,LET,LIST,MAP',REGION=768K,
   10       IEF653I SUBSTITUTION JCL - DSN=SYS1.FORTGLIB,DISP=SHR
   12       IEF653I SUBSTITUTION JCL - DSNAME=BEDS.NOZZ.LOAD(NOZZLE),UNIT=SYSDA,DISP=(SHR,PASS),
   13       IEF653I SUBSTITUTION JCL - SYSOUT=*
   16       IEF686I DDNAME REFERRED TO ON DDNAME KEYWORD IN PRIOR STEP WAS NOT RESOLVED
IEF236I ALLOC. FOR UBSCMWSG FORT STEP1
IEF237I 452  ALLOCATED TO STEPLIB
IEF237I JES2 ALLOCATED TO SYSPRINT
IEF237I VIO  ALLOCATED TO SYSLIN
IEF237I 790  ALLOCATED TO SYSIN
IEF237I 465  ALLOCATED TO SYS00516
IEF142I UBSCMWSG FORT STEP1 - STEP WAS EXECUTED - COND CODE 0000
IEF285I    SYS1.FORTGLNK                                   KEPT
IEF285I    VOL SER NOS= SYSLIB.
IEF285I    JES2.JOB03783.S00101                            SYSOUT
IEF285I    SYS84327.T014914.RA000.UBSCMWSG.LOADSET         PASSED
IEF285I    BEDS.NOZZ.FORT                                  KEPT
IEF285I    VOL SER NOS= COMM24.
IEF285I    CATALOG.NONVSAM.COMMERCL                        KEPT
IEF285I    VOL SER NOS= CTLGV1.

**************************************************************************************************************************
*                                                                                                                        *
*                                                 DOME  PETROLEUM  LIMITED                                               *
*                                                                                                                        *
*   STEP NO.  01            STEP INIT TIME  01:49:14    STORAGE USED   0136K(V) STEP CPU TIME 00:00:01   STEP COND CODE 0000  *
*   STEP NAME FORT          STEP END TIME   01:49:21                                                                     *
*   PGM NAME  IGIFORT       ELAPSED TIME    00:00:06                                                                     *
*                                                                                                                        *
*                                                      EXCP STATISTICS                                                   *
*                                                                                                                        *
*       UNIT   COUNT      UNIT   COUNT      UNIT   COUNT      UNIT   COUNT      UNIT   COUNT      UNIT   COUNT      UNIT   COUNT  *
*                                                                                                                        *
*       452       73      FFF      899      790       26      465        0                                               *
*                                                                                                                        *
*   PAGE-INS          0     PAGE-OUTS               0                                                                    *
*                                                                                                                        *
**************************************************************************************************************************

IEF236I ALLOC. FOR UBSCMWSG LKED STEP1
IEF237I 452  ALLOCATED TO SYSLIB
IEF237I 452  ALLOCATED TO
IEF237I 78F  ALLOCATED TO SYSLMOD
IEF237I 465  ALLOCATED TO SYS00518
IEF237I JES2 ALLOCATED TO SYSPRINT
IEF237I VIO  ALLOCATED TO SYSUT1
IEF237I VIO  ALLOCATED TO SYSLIN
IEF237I DMY  ALLOCATED TO
IEF142I UBSCMWSG LKED STEP1 - STEP WAS EXECUTED - COND CODE 0000
IEF285I    SYS1.FORTGLIB                                   KEPT
IEF285I    VOL SER NOS= SYSLIB.
IEF285I    SYS1.FORTGLIB                                   KEPT
IEF285I    VOL SER NOS= SYSLIB.
IEF285I    BEDS.NOZZ.LOAD                                  PASSED
IEF285I    VOL SER NOS= COMM40.
IEF285I    CATALOG.NONVSAM.COMMERCL                        KEPT
IEF285I    VOL SER NOS= CTLGV1.
IEF285I    JES2.JOB03783.S00102                            SYSOUT
```

```
IEF285I   SYS84327.T014914.RA000.UBSCMWSG.SYSUT1          DELETED
IEF285I   SYS84327.T014914.RA000.UBSCMWSG.LOADSET         DELETED
****************************************************************************************************
*                                                  DOME  PETROLEUM  LIMITED                          *
*  STEP NO.  02            STEP INIT TIME  01:49:21   STORAGE USED   0264K(V) STEP CPU TIME 00:00:00   STEP COND CODE 0000  *
*  STEP NAME LKED          STEP END TIME   01:49:25                                                  *
*  PGM NAME  IEWL          ELAPSED TIME    00:00:04                                                  *
*                                                     EXCP STATISTICS                                *
*      UNIT   COUNT    UNIT   COUNT    UNIT   COUNT    UNIT   COUNT    UNIT   COUNT    UNIT   COUNT    UNIT   COUNT  *
*      452     143     452       0     78F      53     465       0     FFF      62     FFF     899                  *
*  PAGE-INS         0     PAGE-OUTS             0                                                    *
****************************************************************************************************
IEF285I   BEDS.NOZZ.LOAD                                  KEPT
IEF285I   VOL SER NOS= COMM40.
****************************************************************************************************
*                                                  DOME  PETROLEUM  LIMITED                          *
*          JOB NAME   UBSCMWSG   JOB READ TIME  01:49:12     JOB INIT TIME  01:49:14     JOB ELAPSED TIME   00:00:11  *
*          JOB CLASS  K          JOB READ DATE  84.327       JOB INIT DATE  84.327       TIME IN SYSTEM     00:00:13  *
*          JOB PRTY   09         SYSTEM ID      C5DP         JOB END TIME   01:49:25     JOB CPU TIME       00:00:01  *
****************************************************************************************************
```

```
FORTRAN IV G1  RELEASE 2.0          MAIN           DATE = 84327         01/49/16              PAGE 0001
                  C
                  C**************************************************
                  C
                  C     GENERATE DATA TO USE SAP IV FOR NOZZLES
                  C
                  C**************************************************
                  C
0001                    IMPLICIT REAL*8 (A-H,O-Z)
                  C
0002                    COMMON /GT1/ A ( 20000 )
                  C
0003                    DIMENSION IHED  ( 12 )
0004                    DIMENSION IHEDD ( 12 )
                  C
                  C**************************************************
                  C
0005                    NMAX = 20000
                  C
                  C**************************************************
                  C
0006                    IR = 5
0007                    IW = 6
0008                    IWDD  = 0
0009                    IWDD1 = 0
0010                    IWDD2 = 0
0011                    IWDD3 = 0
0012                    IWDD4 = 0
0013                    IWDD5 = 0
0014                    IWDD6 = 0
0015                    IWDD7 = 0
0016                    IWDD8 = 0
0017                    IWDD9 = 0
                  C
                  C**************************************************
                  C
                  C     R E A D   F I R E S T   S E T
                  C
                  C
                  C
                  C**************************************************
                  C
0018                    READ ( IR , 100 ) ( IHEDD ( I ) , I = 1 , 12 )
0019                    READ ( IR , 101 ) NRING,NTHIC,NITHW,NWF,NXF,NZF
0020                    READ ( IR , 102 ) ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN
                  C
                  C**************************************************
                  C
                  C
0021                    NCOLN = 1
                  C
                  C
                  C**************************************************
                  C
                  C
                  C**************************************************
                  C
0022                    DO 1 I = 1 , 12
0023                    IHED ( I ) = IHEDD ( I )
```

```
FORTRAN IV G1  RELEASE 2.0           MAIN              DATE = 84327          01/49/16             PAGE 0002

 0024                1 CONTINUE
               C
               C
 0025                  CALL       SUB1 (NRING,NTHIC,NITHW,NWF,NXF,NZF,
                     1                  ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN,
                     2                  NMAX,NCOLN,IHED,
                     3                  IR,IW,IWDD,
                     4                  IWDD1,IWDD2,IWDD3,IWDD4,
                     5                  IWDD5,IWDD6,IWDD7,IWDD8,IWDD9)
               C
               C
 0026              100 FORMAT(12A4)
 0027              101 FORMAT(16I5)
 0028              102 FORMAT(8F10.0)
               C
               C
 0029                  STOP
 0030                  END
```

```
FORTRAN IV G1  RELEASE 2.0            MAIN              DATE = 84327          01/49/16                PAGE 0003

  *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
  *OPTIONS IN EFFECT*  NAME = MAIN     , LINECNT =       60
  *STATISTICS*    SOURCE STATEMENTS =        30,PROGRAM SIZE =      1016
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G1  RELEASE 2.0           SUB1              DATE = 84327          01/49/16                PAGE 0001
 0001                      SUBROUTINE  SUB1 (NRING,NTHIC,NITHW,NWF,NXF,NZF,
                          1               ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN,
                          2               NMAX,NCOLN,IHED,
                          3               IR,IW,IWDD,
                          4               IWDD1,IWDD2,IWDD3,IWDD4,
                          5               IWDD5,IWDD6,IWDD7,IWDD8,IWDD9)
                     C
 0002                      IMPLICIT REAL*8 (A-H,O-Z)
                     C
                     C
 0003                      COMMON /GT1/ A ( 1 )
                     C
 0004                      DIMENSION IHED ( 12 )
 0005                      DIMENSION IER ( 20 )
                     C
 0006                      ACC = 0.000001
                     C
 0007                      NWEB = ( 360. + ACC ) / ANGW
 0008                      F1   = NWEB * ANGW - 360.
 0009                      IF ( F1 .LT. 0.0 ) F1 = - F1
 0010                      IF ( F1 .GT. ACC ) IER ( 1 ) = 1
                     C
 0011                      NWEBF = 2 * ( ANGF + ACC ) / ANGW + 1
 0012                      F1    = ( NWEBF - 1 ) * ANGW - 2. * ANGF
 0013                      IF ( F1 .LT. 0.0 ) F1 = - F1
 0014                      IF ( F1 .GT. ACC ) IER ( 2 ) = 1
                     C
 0015                      NWFS = ( 180. - ANGF + ACC ) / ANGW + 1
                     C
 0016                      NPRG = 3 * NWEB * NRING
 0017                      NERG = ( 6 * NRING - 4 ) * NWEB
                     C
 0018                      NR1  = NRING - 1
 0019                      NXF2 = 2 * NXF
 0020                      NR2  = NRING + 2
 0021                      NZF1 = NZF + 1
 0022                      NXNR = 2 * NXF + NRING
                     C
 0023                      NWDD = ( NWEBF - 1 ) / ( NWF - 1 )
                     C
 0024                      NPOIN = NPRG + 2 * NXF * NWEBF +
                          1        ( NWEBF * NR2 + 2 * NWF * ( NXF - 1 ) ) * NZF
                     C
 0025                      NELEM = NERG + 2 * NXF * ( NWEBF - 1 ) +
                          1        ( NWEBF - 4 ) * NZF * NR2 +
                          2        ( NXNR - 1 ) * NZF * NWF
                     C
 0026                      N1  = 1
 0027                      N2  = N1  + NR1
 0028                      N3  = N2  + NRING
 0029                      N4  = N3  + NXF2
 0030                      N5  = N4  + NZF
 0031                      N6  = N5  + 3 * NITHW
 0032                      N7  = N6  + NWF
 0033                      N8  = N7  + NR2
 0034                      N9  = N8  + NTHIC
 0035                      N10 = N9  + NWEB
 0036                      N11 = N10 + NPOIN
 0037                 N12 = N11 + NPOIN
 0038                 N13 = N12 + NPOIN
 0039                 N14 = N13 + 4 * NELEM
 0040                 N15 = N14 + NWF * NZF1 * NXNR
 0041                 N16 = N15 + NWEBF
 0042                 N17 = N16 + NELEM
 0043                 N18 = N17 + NPOIN
 0044                 N19 = N18 + NRING
 0045                 N20 = N19 + NELEM
                C
 0046                 IF ( N20 .GT. NMAX ) GO TO 1
                C
 0047                 CALL        RED2 ( A(N1),A(N2),A(N3),A(N4),
                     1                   NR1,NRING,NXF2,NZF,NXF,
                     2                   ANGF,EFOUN,HFOUN,RADIS,ARDIO,
                     3                   IR,IW,IWDD1 )
                C
 0048                 CALL        RED3 ( A(N5),A(N6),A(N7),A(N8),A(N18),
                     1                   NITHW,NWF,NR2,NTHIC,NRING,
                     2                   THIS,THOS,THFP,THFPI,
                     3                   IR,IW )
                C
 0049                 CALL        WEB1 ( A(N9),A(N15),
                     1                   NWEB,NWEBF,NWDD,IW,IWDD2 )
                C
 0050                 CALL        COR1 ( A(N2),A(N9),A(N10),A(N11),A(N12),
                     1                   NRING,NWEB,NPOIN,ANGW,RADIS,ARDIO,IW,IWDD3 )
                C
 0051                 CALL        COR2 ( A(N3),A(N4),A(N9),A(N10),A(N11),A(N12),
                     1                   A(N14),A(N15),
                     2                   NXF2,NZF,NWEB,NPOIN,NWF,NZF1,NXNR,NWEBF,
                     3                   NWFS,NRING,NXF,NPRG,IW,IWDD4 )
                C
 0052                 CALL        TOP1 ( A(N9),A(N13),
                     1                   NWEB,NELEM,NRING,IW,IWDD5 )
                C
 0053                 CALL        TOP2 ( A(N9),A(N13),A(N14),
                     1                   NWEB,NELEM,NWF,NZF1,NXNR,
                     2                   NXF,NWEBF,NPRG,NERG,NRING,NWFS,
                     3                   IW,IWDD6 )
                C
 0054                 CALL        THIH ( A(N5),A(N6),A(N7),A(N8),
                     1                   A(N16),A(N18),
                     2                   NITHW,NWF,NR2,NTHIC,NELEM,NRING,
                     3                   THIS,THOS,THFP,THFPI,
                     4                   NWEB,NWEBF,NERG,NXF,NZF1,NWFS,
                     5                   NXNR,IW,IWDD7 )
                C
 0055                 CALL        IDVL ( A(N14),A(N17),
                     1                   NWF,NZF1,NXNR,NPOIN,
                     2                   NXF,NZF,NWEBF,NPRG,NRING,
                     3                   IW,IWDD8 )
                C
 0056                 CALL        INPTW1 (A(N1), A(N5),A(N6),A(N7),A(N8),A(N18),
                     1                   NR1, NITHW,NWF,NR2,NTHIC,NRING,
                     2                   NXF,NZF,THIS,THOS,THFP,THFPI,
                     3                   ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN,
                     4                   NWEB,NWEBF,NWFS,NPRG,NERG,NPOIN,NELEM,
                  5                  IHEDD,IW )
              C
0057                CALL       PRESS ( A(N19),
                  1                  NELEM,NRING,ANGW,IR,IW,IWDD9 )
              C
0058                CALL       INPTW2 (A(N1), A(N5),A(N6),A(N7),A(N8),A(N18),
                  1                  A(N19),
                  2                  NR1, NITHW,NWF,NR2,NTHIC,NRING,
                  3                  NXF,NZF,THIS,THOS,THFP,THFPI,
                  4                  ANGW,RADIS,ARDIO,ANGF,EFOUN,HFOUN,
                  5                  NWEB,NWEBF,NWFS,NPRG,NERG,NPOIN,NELEM,
                  6                  IHEDD,IW )
              C
0059                CALL       SAPW ( A(N10),A(N11),A(N12),A(N13),A(N16),A(N17),
                  1                 A(N19),
                  2                 NPOIN,NELEM,NCOLN,IHED )
              C
0060                RETURN
              C
0061              1 CONTINUE
              C
0062                WRITE ( IW , 201 ) N20 , NMAX
              C
0063            201 FORMAT (1H ,6HN20 = ,I5,24H IS GREATER THAN NMAX = ,I5)
              C
              C
0064                RETURN
0065                END
```

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FORTRAN IV G1  RELEASE 2.0               SUB1               DATE = 84327          01/49/16                PAGE 0004

     *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
     *OPTIONS IN EFFECT*  NAME = SUB1    , LINECNT =       60
     *STATISTICS*    SOURCE STATEMENTS =        65,PROGRAM SIZE =      4520
     *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
0001                SUBROUTINE RED2 ( BR , XR , XFOUND , ZF ,
              1                  NR1,NRING,NXF2,NZF,NXF,
              2                  ANGF,EFOUN,HFOUN,RADIS,ARDIO,
              3                  IR,IW,IWDD1 )
           C
0002                IMPLICIT REAL*8 (A-H,O-Z)
           C
           C
           C        CALCULATE DIMENSIONS OF XR , ZF AND XFOUND
           C
0003                COMMON /GT1/ A ( 1 )
           C
0004                DIMENSION BR(NR1),XR(NRING)
0005                DIMENSION XFOUND(NXF2),ZF(NZF)
           C
           C
           C*************************************************
           C
           C
           C        R E A D   S E C O N D   S E T
           C
           C
           C
           C*************************************************
           C
           C        SEE PAGE 12
           C
0006                READ ( IR , 103 ) ( BR ( I ) , I = 1 , NR1 )
           C
           C*************************************************
           C
           C
           C        X - COORDINATES OF RINGS
           C
0007                XD = 0.
0008                DO 1 I = 1 , NR1
0009                XD = XD + BR ( I )
0010              1 CONTINUE
0011                XR( 1 ) = - 0.5 * XD
0012                DO 2 I = 1 , NR1
0013                XR ( I + 1 ) = XR ( I ) + BR ( I )
0014              2 CONTINUE
           C
0015                XD = EFOUN / NXF
0016                XFOUND (       1 ) = XR (   1     ) - EFOUN
0017                XFOUND ( NXF + 1 ) = XR ( NRING ) + XD
0018                DO 3 I = 2 , NXF
0019                XFOUND ( I       ) = XFOUND (       1 ) + ( I - 1 ) * XD
0020                XFOUND ( I + NXF ) = XFOUND ( NXF + 1 ) + ( I - 1 ) * XD
0021              3 CONTINUE
           C
           C        Z COORDINATES OF FOUNDATION
           C        SEE PAGE 11
           C
0022                PI = 4 * ATAN ( 1. )
           C
0023                THETA = ANGF * PI / 180.
           C
```

```
 0024              ZF ( NZF ) = ( RADIS + ARDIO ) * DCOS ( THETA ) + HFOUN
 0025              ZD = ( ZF ( NZF ) - ( RADIS + ARDIO ) ) / NZF
             C
 0026              DO 4 I = 1 , NZF
 0027              ZF ( I ) = RADIS + ARDIO + I * ZD
 0028            4 CONTINUE
             C
             C
 0029              IF ( IWDD1 .EQ. 0  ) RETURN
             C
 0030              WRITE ( IW , 301 ) ( XR     ( I ) , I = 1 , NRING )
 0031              WRITE ( IW , 302 ) ( XFOUND ( I ) , I = 1 , NXF2  )
 0032              WRITE ( IW , 303 ) ( ZF     ( I ) , I = 1 , NZF   )
             C
 0033          103 FORMAT(8F10.0)
             C
 0034          301 FORMAT(1H ,29H X-COORDINATES OF RINGES      ,/,10F10.4,/)
 0035          302 FORMAT(1H ,29H X-COORDINATES OF FOUNDATION ,/,10F10.4,/)
 0036          303 FORMAT(1H ,29H Z-COORDINATES OF FOUNDATION ,/,10F10.4,/)
             C
 0037              RETURN
 0038              END
```

```
   *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
   *OPTIONS IN EFFECT*  NAME = RED2     , LINECNT =       60
   *STATISTICS*    SOURCE STATEMENTS =        38,PROGRAM SIZE =      1992
   *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G1  RELEASE 2.0          RED3           DATE = 84327          01/49/16            PAGE 0001
  0001                   SUBROUTINE RED3 ( ITHW , ITHWF, ITHD , THICK , ITHR ,
                         1                 NITHW,NWF,NR2,NTHIC,NRING,
                         2                 THIS,THOS,THFP,THFPI,
                         3                 IR,IW )
                 C
  0002                   IMPLICIT REAL*8 (A-H,O-Z)
                 C
                 C
                 C       READ THICKNESSES
                 C
  0003                   COMMON /GT1/ A ( 1 )
                 C
  0004                   DIMENSION ITHW(3,NITHW),ITHWF(NWF)
  0005                   DIMENSION ITHD(NR2),THICK(NTHIC)
  0006                   DIMENSION ITHR(NRING)
                 C
                 C
                 C*************************************************
                 C
                 C
                 C       R E A D   T H I R D    S E T
                 C
                 C
                 C
                 C*************************************************
                 C
                 C       SEE PAGE 12
                 C
  0007                   READ ( IR , 104 ) THIS , THOS , THFP , THFPI
                 C
  0008                   READ ( IR , 105 ) ( ITHR  ( I ) , I = 1 , NRING )
                 C
  0009                   READ ( IR , 106 ) ( ITHW ( 1 , J ) , J = 1 , NITHW )
  0010                   READ ( IR , 107 ) ( ITHW ( 2 , J ) , J = 1 , NITHW )
  0011                   READ ( IR , 108 ) ( ITHW ( 3 , J ) , J = 1 , NITHW )
                 C
  0012                   READ ( IR , 109 ) ( ITHWF ( I ) , I = 1 , NWF   )
                 C
  0013                   READ ( IR , 110 ) ( ITHD  ( I ) , I = 1 , NR2   )
                 C
  0014                   READ ( IR , 111 ) ( THICK ( I ) , I = 1 , NTHIC )
                 C
                 C*************************************************
                 C
                 C
  0015               104 FORMAT(4F10.0)
  0016               105 FORMAT(26I3)
  0017               106 FORMAT(26I3)
  0018               107 FORMAT(26I3)
  0019               108 FORMAT(26I3)
  0020               109 FORMAT(26I3)
  0021               110 FORMAT(26I3)
  0022               111 FORMAT(8F10.0)
                 C
  0023                   RETURN
  0024                   END
  *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
  *OPTIONS IN EFFECT*  NAME = RED3     , LINECNT =       60
  *STATISTICS*    SOURCE STATEMENTS =        24,PROGRAM SIZE =      1388
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G1  RELEASE 2.0          WEB1             DATE = 84327          01/49/16                PAGE 0001

 0001                 SUBROUTINE WEB1 ( IWEB , IWEBF,
                     1                 NWEB,NWEBF,NWDD,IW,IWDD2 )
                C
 0002                 IMPLICIT REAL*8 (A-H,O-Z)
                C
                C
                C     RELATE TWO DIFFERENT WEB NUMBERING SYSTEM
                C     AND INDICATES WEBS IN FOUNDATION
                C
 0003                 COMMON /GT1/ A ( 1 )
                C
 0004                 DIMENSION IWEB(NWEB)
 0005                 DIMENSION IWEBF(NWEBF)
                C
 0006                 IC = 1
 0007                 IWEB ( IC ) = 1
                C
 0008                 DO 1 I = 2 , NWEB , 2
 0009                 IC = IC + 1
 0010                 IWEB ( IC ) = I
 0011               1 CONTINUE
                C
 0012                 N1 = NWEB
 0013                 N2 = NWEB / 2
 0014                 N3 = 2 * N2
 0015                 IF ( N1 .EQ. N3 ) N1 = NWEB - 1
                C
 0016                 IK = O
 0017                 DO 2 I = 1 , NWEB , 2
 0018                 IK = IK + 1
 0019                 NN = N1 - 2 * ( IK - 1 )
 0020                 IF ( NN .LE. 1 ) GO TO 3
 0021                 IC = IC + 1
 0022                 IWEB ( IC ) = NN
 0023               2 CONTINUE
 0024               3 CONTINUE
                C
 0025                 DO 4 I = 1 , NWEBF
 0026                 IWEBF ( I ) = O
 0027               4 CONTINUE
                C
 0028                 DO 5 I = 1 , NWEBF , NWDD
 0029                 IWEBF ( I ) = I
 0030               5 CONTINUE
                C
 0031                 IF ( IWDD2 .EQ. O ) RETURN
                C
 0032                 WRITE ( IW , 201 )
 0033                 WRITE ( IW , 202 )
 0034                 DO 11 I = 1 , NWEB
 0035                 WRITE ( IW , 101 ) I ,  IWEB ( I )
 0036              11 CONTINUE
 0037                 WRITE ( IW , 203 )
 0038                 WRITE ( IW , 204 )
 0039                 DO 12 I = 1 , NWEBF
 0040                 WRITE ( IW , 101 ) I ,  IWEBF ( I )
 0041              12 CONTINUE
                C
```

```
FORTRAN IV G1  RELEASE 2.0           WEB1           DATE = 84327         01/49/16             PAGE 0002

 0042              101 FORMAT(1H ,1X,I2,12X,I2)
                 C
 0043              201 FORMAT(1H ,11HEL. WEB NO.,2X,12HNODE WEB NO.,/)
 0044              202 FORMAT(1H ,5H( L ),8X,6H( LD ),/)
 0045              203 FORMAT(1H ,11H  WEB NO.  ,2X,12HFOUN WEB NO.,/)
 0046              204 FORMAT(1H ,5H( I ),8X,6H( ID ),/)
                 C
 0047                  RETURN
 0048                  END
```

```
FORTRAN IV G1  RELEASE 2.0                WEB1                DATE = 84327          01/49/16                  PAGE 0003

    *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
    *OPTIONS IN EFFECT*  NAME = WEB1     , LINECNT =       60
    *STATISTICS*     SOURCE STATEMENTS =        48,PROGRAM SIZE =      1304
    *STATISTICS*   NO DIAGNOSTICS GENERATED
```

```
      SUBROUTINE COR1 ( XR , IWEB , X , Y, Z ,
     1                  NRING,NWEB,NPOIN,ANGW,RADIS,ARDIO,IW,IWDD3 )
C
      IMPLICIT REAL*8 (A-H,O-Z)
C
C
C     CALCULATE COORDINATES OF ALL NODES
C     ON ALL RINGES ONLY
C
      COMMON /GT1/ A ( 1 )
C
      DIMENSION XR(NRING)
      DIMENSION IWEB(NWEB)
      DIMENSION X(NPOIN),Y(NPOIN),Z(NPOIN)
      DIMENSION RD ( 3 )
C
      PI = 4 * ATAN ( 1. )
C
      RD ( 1 ) = RADIS
      RD ( 2 ) = RD ( 1 ) + 0.5 * ARDIO
      RD ( 3 ) = RD ( 1 ) +       ARDIO
C
      IF ( IWDD3 .NE. O ) WRITE ( IW , 201 )
C
      DO 3 K = 1 , NWEB
      LD = IWEB ( K )
      THETA = - ( K - 1 ) * ANGW
      IF ( IWDD3 .NE. O ) WRITE ( IW , 101 ) K , THETA
      THETA = THETA * PI / 180.
      SI = DSIN ( THETA )
      CS = DCOS ( THETA )
      IF ( IWDD3 .NE. O ) WRITE ( IW , 102 ) K , THETA , SI , CS
      J1 = 3 * NRING * ( LD - 1 )
      DO 2 I = 1 , NRING
      I1 = 3 * ( I - 1 )
      DO 1 J = 1 , 3
      JJ = J1 + I1 + J
      X ( JJ ) = XR ( I )
      Y ( JJ ) =   RD ( J ) * SI
      Z ( JJ ) = - RD ( J ) * CS
      IF ( IWDD3 .NE. O ) WRITE ( IW , 103 )
     1     K,LD,J1,I,I1,J,JJ,X(JJ),Y(JJ),Z(JJ)
    1 CONTINUE
    2 CONTINUE
    3 CONTINUE
C
  101 FORMAT(1H ,7HK THETA,I5,F10.3)
  102 FORMAT(1H ,18HK THETA SIN COSINE,I5,3F10.5)
  103 FORMAT(1H ,23HK LD J1 I I1 J JJ X Y Z,5X,7I4,3F10.5)
C
  201 FORMAT(1H ,34HCOORDINATES OF NODES ON RINGS ONLY,/)
C
      RETURN
      END
```

```
FORTRAN IV G1  RELEASE 2.0            COR1            DATE = 84327          01/49/16              PAGE 0002

  *OPTIONS IN EFFECT*  NOTERM,ID,EBCDIC,SOURCE,NOLIST,NODECK,LOAD,NOMAP,NOTEST
  *OPTIONS IN EFFECT*  NAME = COR1     , LINECNT =       60
  *STATISTICS*     SOURCE STATEMENTS =        38,PROGRAM SIZE =      1640
  *STATISTICS*  NO DIAGNOSTICS GENERATED
```

```
FORTRAN IV G1  RELEASE 2.0          COR2               DATE = 84327          01/49/16                  PAGE 0001
 0001                   SUBROUTINE COR2 ( XFOUND,ZF,IWEB,X,Y,Z,
                       1                  IFOUN,IWEBF,
                       2                  NXF2,NZF,NWEB,NPOIN,NWF,NZF1,NXNR,NWEBF,
                       3                  NWFS,NRING,NXF,NPRG,IW,IWDD4 )
                  C
 0002                   IMPLICIT REAL*8 (A-H,O-Z)
                  C
                  C
                  C     FOUNDATION COORDINATES AND ARRAY IFOUN FOR TOPOLOGY
                  C     OF WEBS IN FOUNDATION
                  C
 0003                   COMMON /GT1/ A ( 1 )
                  C
 0004                   DIMENSION XFOUND(NXF2),ZF(NZF)
 0005                   DIMENSION IWEB(NWEB)
 0006                   DIMENSION X(NPOIN),Y(NPOIN),Z(NPOIN)
 0007                   DIMENSION IFOUN(NWF,NZF1,NXNR),IWEBF(NWEBF)
                  C
                  C     FOUNDATION PLATE
                  C
 0008                   IF ( IWDD4 .NE. O ) WRITE ( IW , 201 )
                  C
 0009                   NWDD = ( NWEBF - 1 ) / ( NWF - 1 )
                  C
 0010                   IC = O
 0011                   DO 5 I = 1 , NWEBF
 0012                   IWF = IWEBF ( I )
 0013                   IF ( I .EQ. IWF ) IC = IC + 1
 0014                   L = NWFS + I - 1
 0015                   LD = IWEB ( L )
 0016                   N = 3 * NRING * ( LD - 1 ) + 3 * 1
 0017                   DO 2 J = 1 , NXF2
 0018                   J1 = NPRG + ( J - 1 ) * NWEBF + I
 0019                   X ( J1 ) = XFOUND ( J )
 0020                   Y ( J1 ) = Y ( N )
 0021                   Z ( J1 ) = Z ( N )
 0022                   IF ( IWDD4 .NE. O ) WRITE ( IW , 101 )
                       1      I,L,LD,N,J,J1,X(J1),Y(J1),Z(J1)
 0023                   IF ( I .NE. IWF ) GO TO 1
 0024                   J2 = J
 0025                   IF ( J .GT. NXF ) J2 = J + NRING
 0026                   IFOUN ( IC , 1 , J2 ) = J1
 0027                 1 CONTINUE
 0028                 2 CONTINUE
 0029                   IF ( I .NE. IWF ) GO TO 4
 0030                   DO 3 J = 1   , NRING
 0031                   J2 = J + NXF
 0032                   IFOUN ( IC , 1 , J2 ) = N + ( J - 1 ) * 3
 0033                 3 CONTINUE
 0034                 4 CONTINUE
 0035                 5 CONTINUE
                  C
                  C     END DIAPHRAGMES
                  C
 0036                   NBOT = NPRG + 2 * NXF * NWEBF
 0037                   NADF = NWEBF * ( 2 + NRING ) + NWF * 2 * ( NXF - 1 )
 0038                   NK1  = NWEBF * ( 1 + NRING ) + NWF * 2 * ( NXF - 1 )
 0039                   NK2  = NWEBF *       NRING   + NWF *     ( NXF - 1 )
```

The ship has 6 degrees of freedom and its motions are fully described both in a fixed and moving (ship's) coordinates. The surface of the ship is defined by the orthogonal grid enclosing the number of poligon surfaces. Nozzle sections is aproximated with straight line segments and an nozzle ring is made of such sections spaced 15 degrees apart and enclossed with tile like poligin surface.

2.2. Ice

Ice is assumed to be nonelastic, homogeneous material of given crushing strength. Ice is modeled by the three dimensional bit matrix where binary value of the each bit represent presence or absence of the ice in the element of space. The size of 0.2 meters of the each element was selected fot those runs.

Ice may be modeled as a circular ice floe of given radius and thickness free floating with six degrees of freedom or as nonmovable ice of any geometric shape.

2.3. Water

Water is assumed to be a viscous fluid with nonlinear damping properties. Other than virtual mass associated with the ship, no inertial properties are considered in this program. Water is assumed to be calm in all cases.

2.4. Ship-Water Interaction

Ship-Water interaction is described by resistance and virtual mass function.

Resistance is defined by these non-linear functions:

$$R = -V_x * abs(V_x) * LBP * (B+2*DFT)/1333$$

$$-sgn(VN) * VN^{2.5} * B * DFT/130 \quad \text{(kNewton)}$$

where $VN = V_x * 1.5 * W/LBP/B/DFT$

$$R_y = -V_y * abs(V_y) * LBP * DFT/4 \quad \text{(kNewton)}$$

$$R_z = -V_z * abs(V_z) * LBP * B/3 \quad \text{(kNewton)}$$

$$R_x = -V_x * abs(V_x) * LBP * B3/67 \quad (kN * M)$$

$$R_y = -V_y * abs(V_y) * LBP3 * B/85 \quad (kN * M)$$

$$R_z = -V_z * abs(V_z) * LBP3 * DFT/67 \quad (kN * M)$$

In the X direction propeller thrust is approximated by following formula:

$$T=kWats*(7.4-V_x*V_x{}^2/1200)/100 \quad \text{(kNewton)}$$

The wave generation during the ship motion is not considered. The mass of the ship including added mass is approximated by following formulas:

$$Q_x=Displ \quad \text{(Tonnes)}$$

$$Q_y=Q_x*1.6 \quad \text{(Tonnes)}$$

$$Q_z=Q_x*2.18 \quad \text{(Tonnes)}$$

$$Q_x=Q_x*(.25*B)^2*2.25 \quad (T * M)$$

$$Q_y=Q_x*(.25*LBP)^2*2.17 \quad (T * M)$$

$$Q_z=Q_x*(.25*LBP)^2*2.17 \quad (T * M)$$

2.5. Ship-Ice Interaction

The ship interacts with ice by crushing it. All boundary layer problems and inertial forces are disregarded. Pressure developed on the hull surface acts always in the direction of the surface vector. The friction force is assumed to be coulombian i.e. friction force is proportional to normal force and has direction oposite to the velocity vector for any of surface elements. The summation of all surface elements over the crushed area determined by the current geometry of the interaction produces the total force vector and moment vector acting on the rigid body of a ship.

The crushed elements are reset in the three dimensional ice matrix at any time interval and file is updated. Current ice shape and the actual ship position are compared to produce a new ice footprint on the ship.

3. ICESIM Programs Description

ICS is the main program that performs all calculations. Calculations are performed for the given time intervals to the specified time limit. At each time interval ship is displaced and rotated according to the projected ship location given by extrapolating previous time intervals. For this position integration is performed to determine hydrostatics forces. Next procedure 'interact' compares ship surface against the ice matrix and for the elements of the surface in the contact components of the ice forces are calculated. From velocity vector for the surface element frictional force vector is calculated. Procedure 'accel' calculates viscous damping forces and acceleration vector.

Description Of Computer Runs

30,000t Displ't 50,000 HP Icebreaker, Single Nozzle:

1. Long'l impact, 15 knots, $\delta c = x$ MPa
2. Bottom impact, 2.5 knots, $\delta c = x$ MPa

30,000t Displ't 50,000 HP Icebreaker, Twin Nozzles:

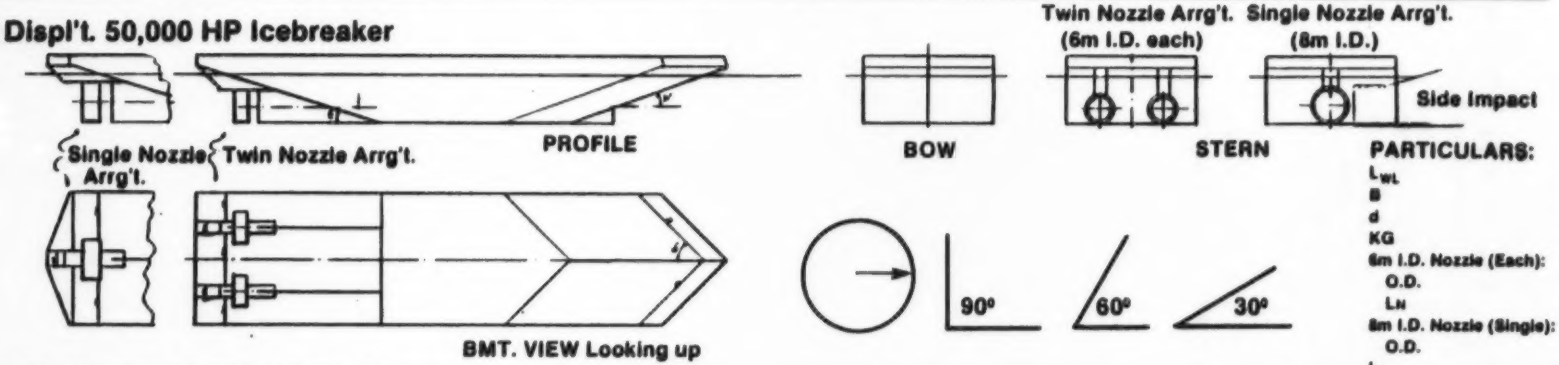
3. Long'l impact, 15 knots, $\delta c = x$ MPa
4. Long'l impact, 10 knots, $\delta c = x$ MPa
5. Long'l impact, 5 knots, $\delta c = x$ MPa
6. Side impact, 2 knots $\delta c = x$ MPa
7. Same as "6" but ice wall-30° Slope
8. Same as "6" but ice wall-60° Slope
9. Btm. impact, 2.5 knots, $\delta c = x$ MPa

3750t Displ't, 8000 HP Icebreaker, Single Nozzle

300,000t Displ't, 2 x 50,000 HP tanker:

10. Long'l impact, 15 knots, $\delta c = x$ MPa
11. Side impact, 2 knots, $\delta c = x$ MPa
12. Side impact, 2 knots, $\delta c = 2 \cdot x$ MPa
13. Btm impact, 2.5 knots, $\delta c = x$ MPa

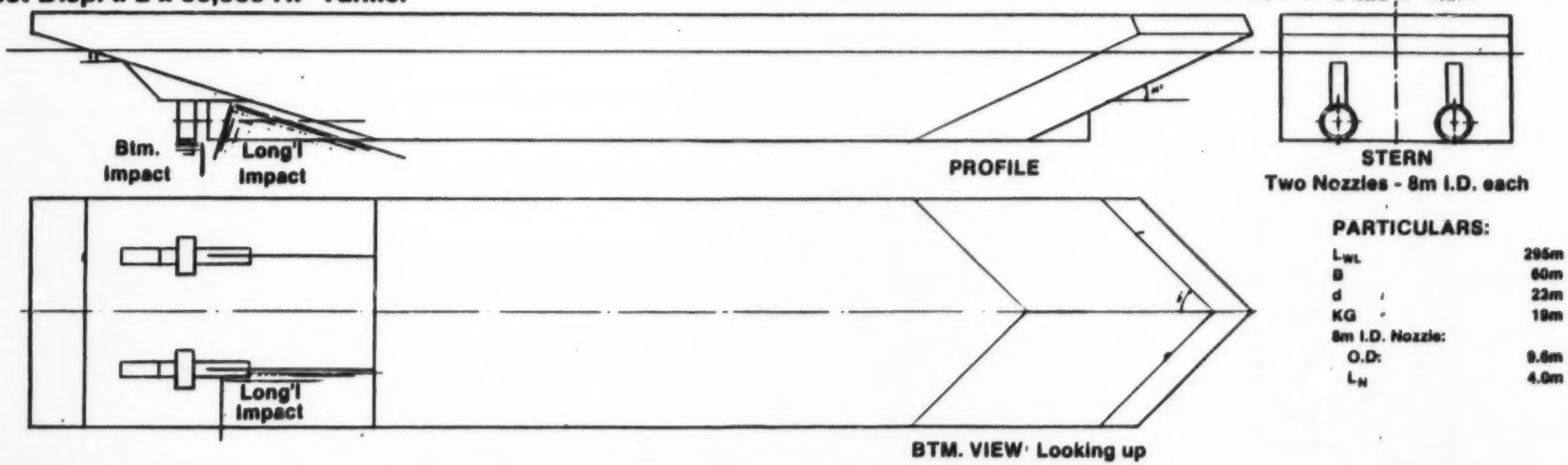
30,000t Displ't. 50,000 HP Icebreaker


Twin Nozzle Arrg't.
(6m I.D. each)
Single Nozzle Arrg't.
(8m I.D.)
Side Impact
Single Nozzle Arrg't.
Twin Nozzle Arrg't.
PROFILE
BOW
STERN
90°
60°
30°
BMT. VIEW Looking up

PARTICULARS:

L_{WL}	120m
B	33m
d	12m
KG	11m
6m I.D. Nozzle (Each):	
O.D.	7.2m
L_N	3.0m
8m I.D. Nozzle (Single):	
O.D.	9.6m
L_N	4.0m

300,000t Displ't. 2 x 50,000 HP Tanker


Btm. Impact
Long'l Impact
PROFILE
STERN
Two Nozzles - 8m I.D. each
Long'l Impact
BTM. VIEW Looking up

PARTICULARS:

L_{WL}	295m
B	60m
d	23m
KG	19m
8m I.D. Nozzle:	
O.D.	9.6m
L_N	4.0m

CANMAR

CANADIAN
MARINE
DRILLING
LIMITED

Strength Requirements
For Nozzles For Ice
Transitting Ships

TITLE: Input Into Nozzle-Ice Interaction Program

FIGURE No.

The following pages document for all of the ICESIM runs, the time history of the quantities listed below:

Angular acceleration in roll, pitch and yaw;
Linear acceleration in sway, surge and heave;
Angular velocities in roll, pitch and yaw;
Linear velocities in surge, sway and heave;
Ice force moment, in x, y, z direction;
Ice force in x, y, z direction;
Angular displacement in roll, pitch and yaw;
Linear displacement in surge, sway and heave.

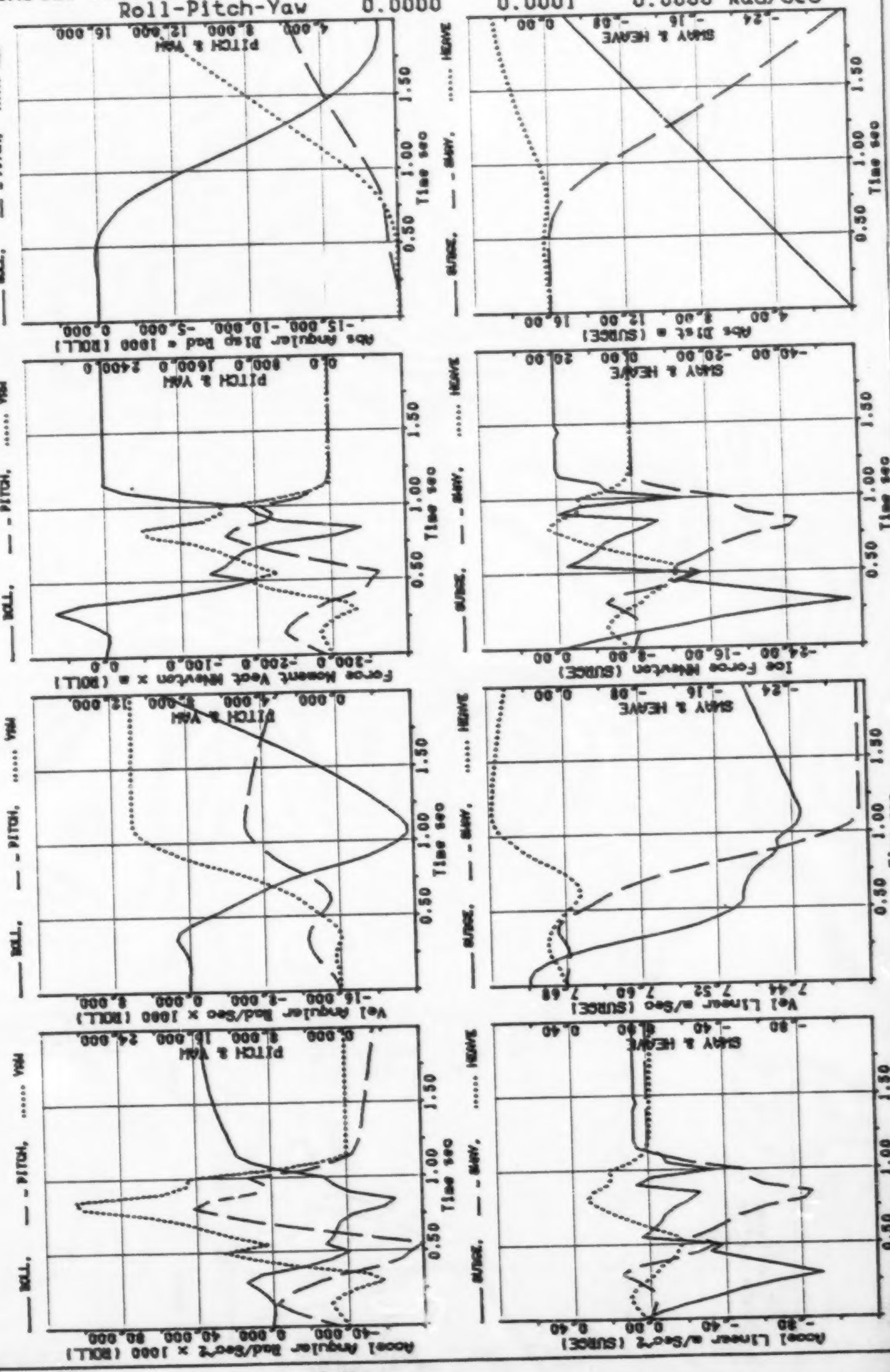
①

NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Thu Nov 15-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Single 8.0 M Nozzle
Head on Inpact 15 knots
Inital Velocity X-Y-Z 7.72 0.00 0.00 m/Sec
Roll-Pitch-Yaw 0.0000 0.0001 0.0000 Rad/Sec

Displacement	31411.5	Tonnes
LCG	-.59	m
VCG	13.00	m
Draft	12.00	m
Propulsion Power	37300.0	kWatt

Ice Compressive Strength 5.00 MPascal
Friction Coefficient 0.00



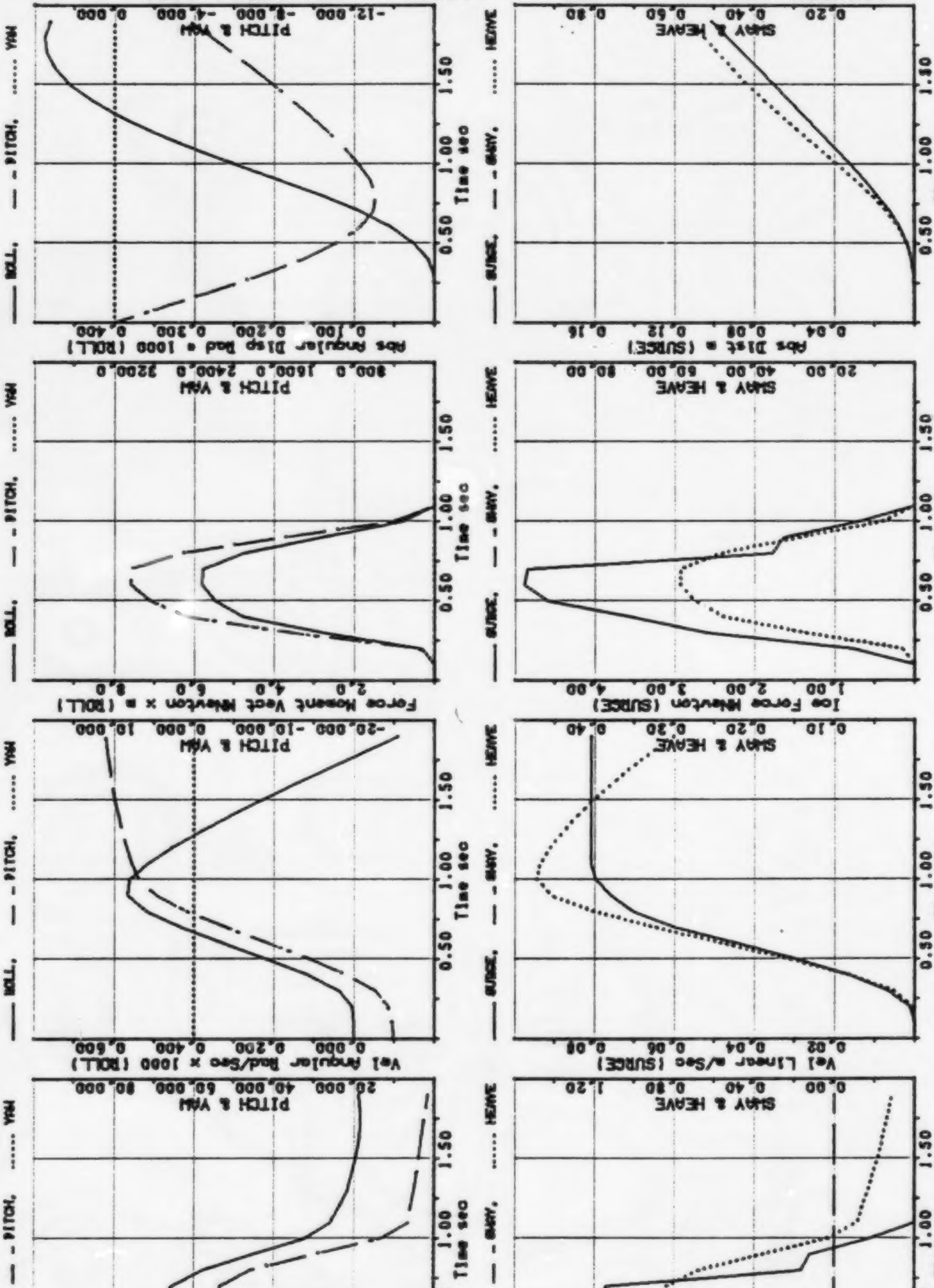
(2)

NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Fri Nov 16-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Single 8.0 M Nozzle
Bottom Impact

Inital Velocity X-Y-Z	0.00	0.00	0.00	m/Sec
Roll-Pitch-Yaw	0.0000	-.0249	0.0000	Rad/Sec

Displacement	31411.5	Tonnes
LCG	-.59	m
VCG	13.00	m
Draft	12.00	m
Propulsion Power	0.0	kWatt
Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



C8

② a.

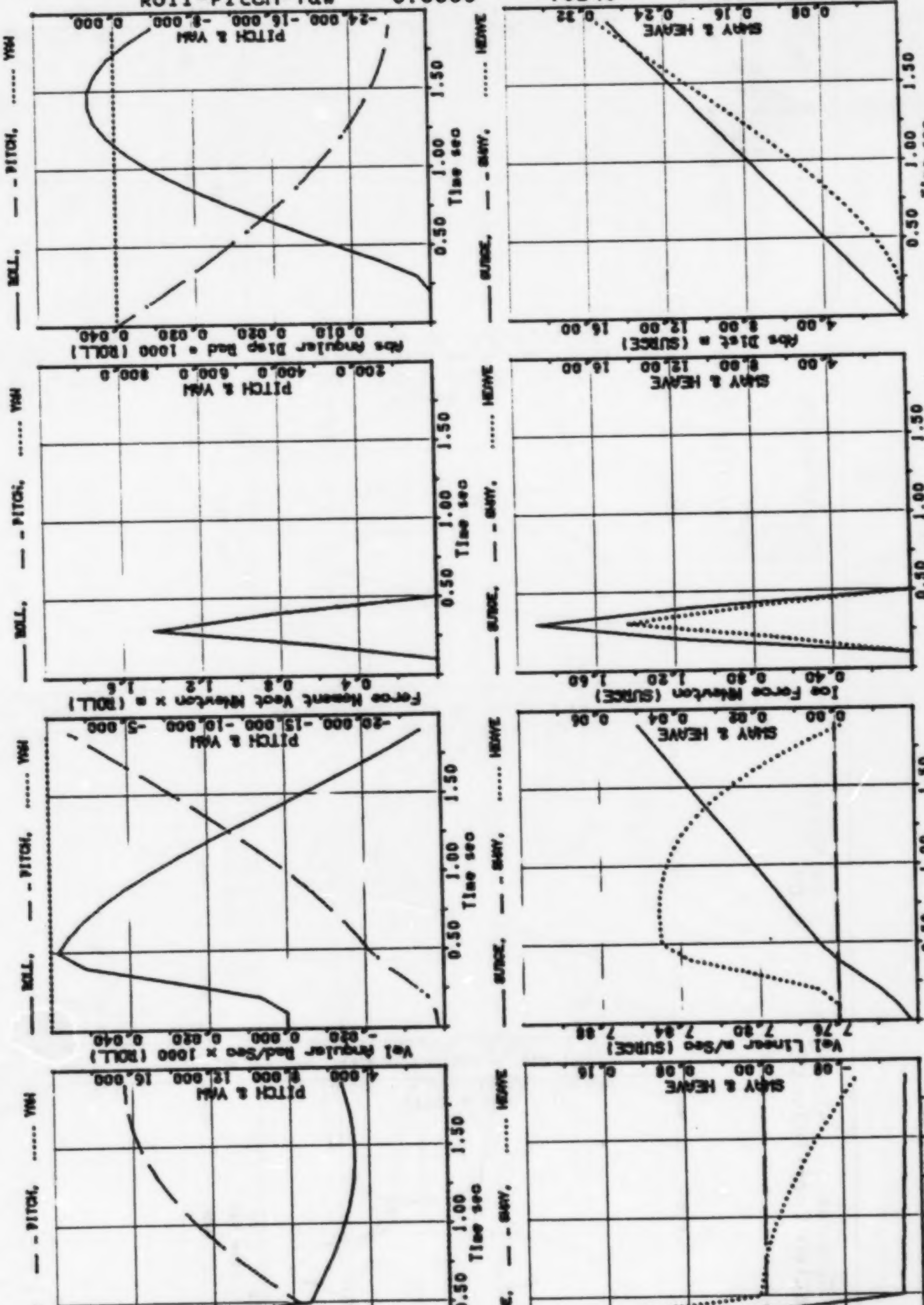
Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Thu Nov 15-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Single 8.0 M Nozzle
Bottom Impact at 15 knots

Inital Velocity X-Y-Z	7.72	0.00	0.00	m/Sec
Roll-Pitch-Yaw	0.0000	-.0246	0.0000	Rad/Sec

Displacement 31411.5 Tonnes
LCG -.59 m
VCG 13.00 m
Draft 12.00 m
Propulsion Power 37300.0 kWatt

Ice Compressive Strength 5.00 MPascal
Friction Coefficient 0.00



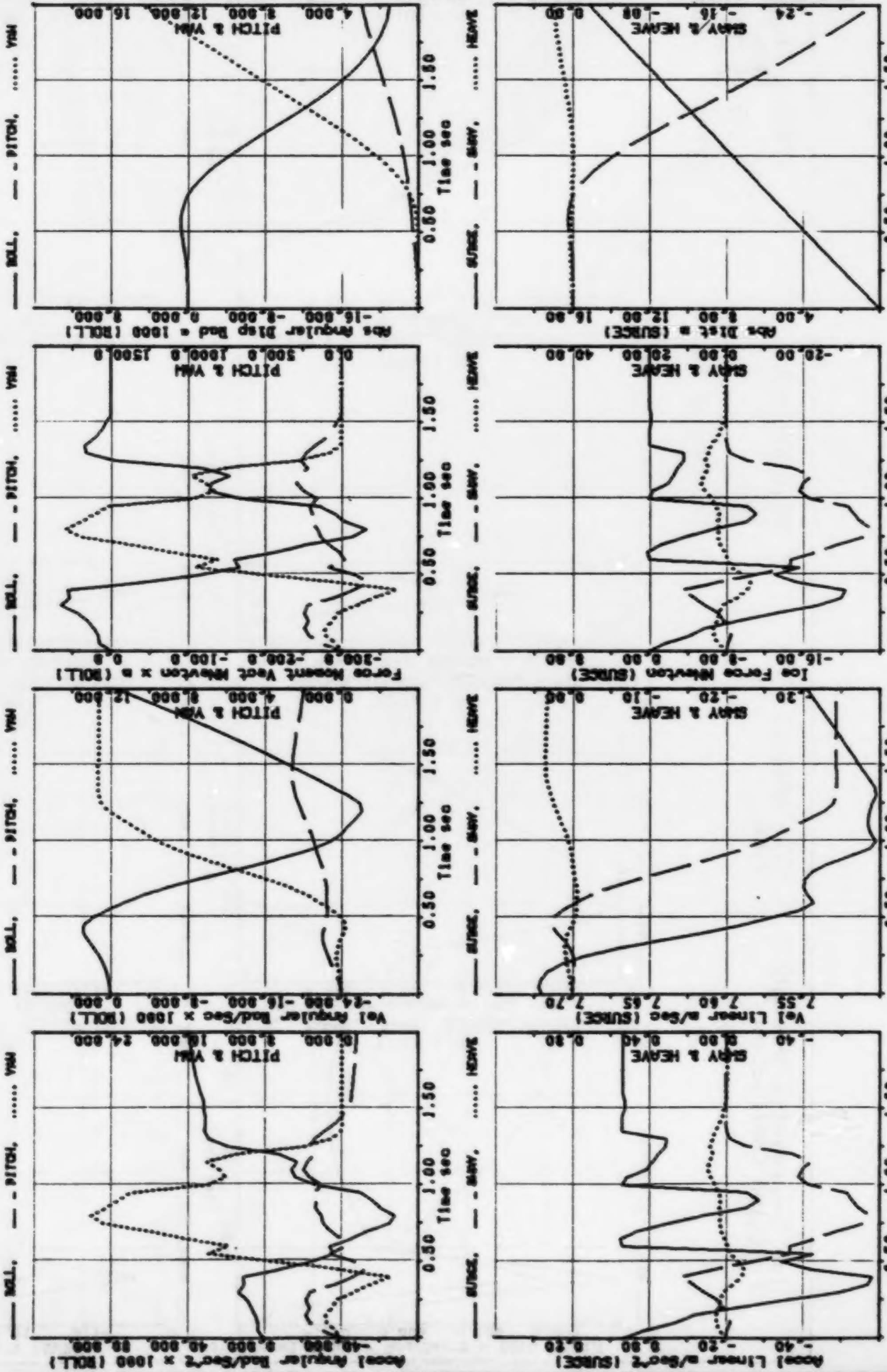
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1

Project No.421 Wed Nov 14-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Twin 6.0 M Nozzles
Head on Inpact

Inital Velocity X-Y-Z	7.72	0.00	0.00	m/Sec
Roll-Pitch-Yaw	0.0000	0.0000	0.0000	Rad/Sec

Displacement	31411.5	Tonnes
LCG	-.59	m
VCG	13.00	m
Draft	12.00	m
Propulsion Power	37300.0	kWatt
Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



C10

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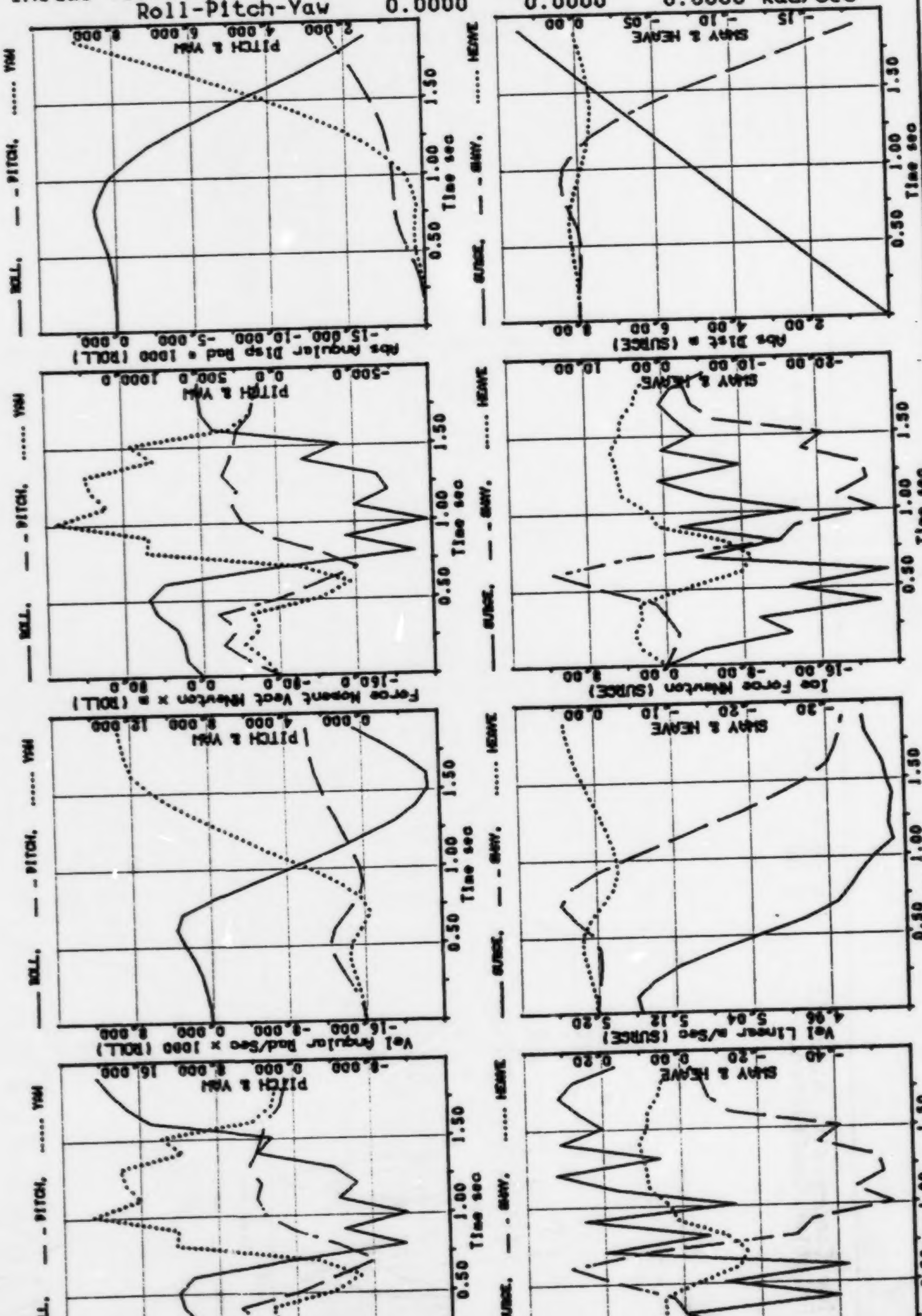
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Wed Nov 14-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Twin 6.0 M Nozzles
Head on Inpact
Inital Velocity X-Y-Z 5.15 0.00 0.00 m/Sec
Roll-Pitch-Yaw 0.0000 0.0000 0.0000 Rad/Sec

Displacement 31411.5 Tonnes
LCG -.59 m
VCG 13.00 m
Draft 12.00 m
Propulsion Power 37300.0 kWatt

Ice Compressive Strength 5.00 MPascal
Friction Coefficient 0.00



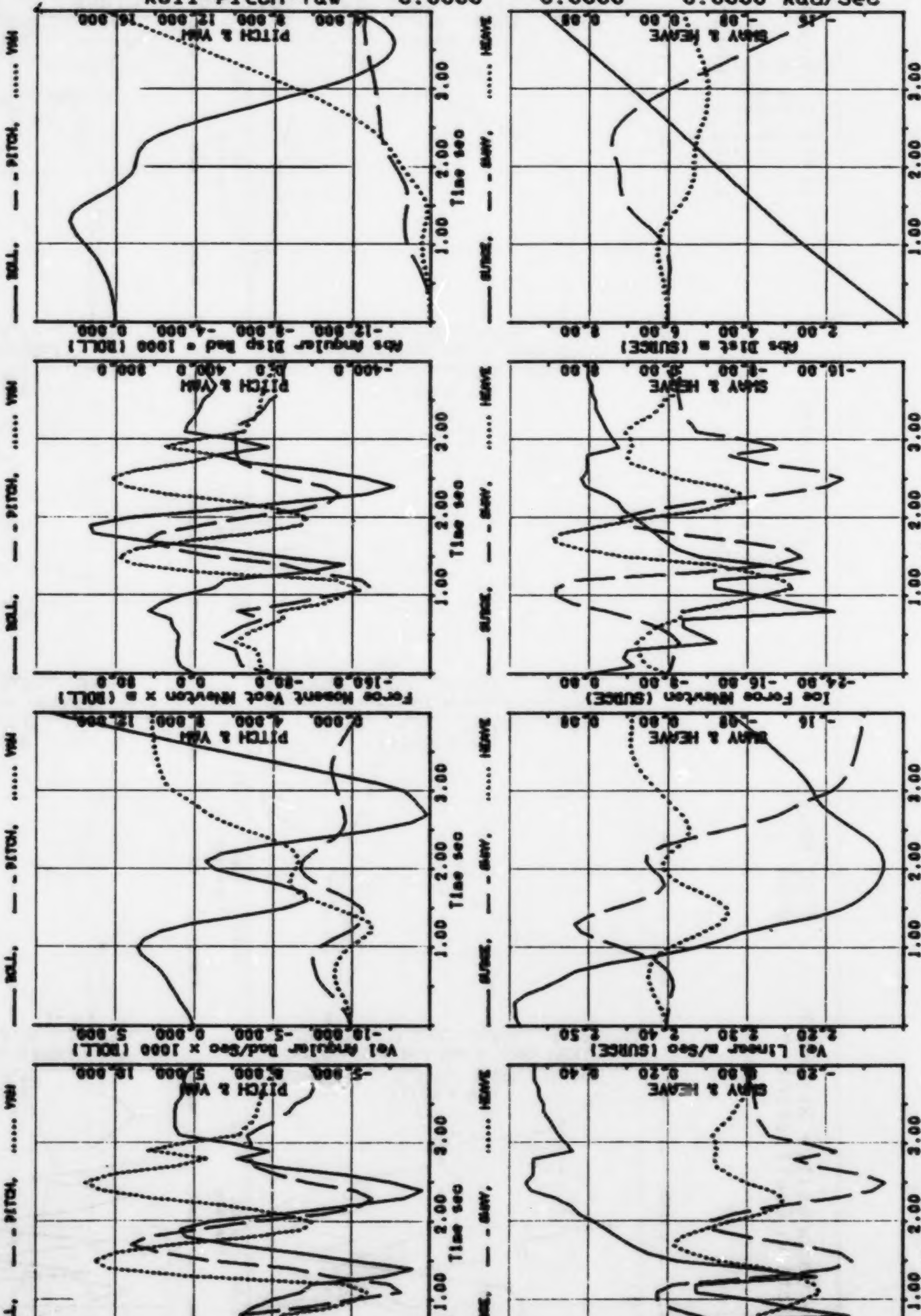
C 11

NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Wed Nov 14-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Twin 6.0 M Nozzles
Head on Inpact

Inital Velocity X-Y-Z	2.59	0.00	0.00	m/Sec
Roll-Pitch-Yaw	0.0000	0.0000	0.0000	Rad/Sec

Displacement	31411.5	Tonnes
LCG	-.59	m
VCG	13.00	m
Draft	12.00	m
Propulsion Power	37300.0	kWatt
Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



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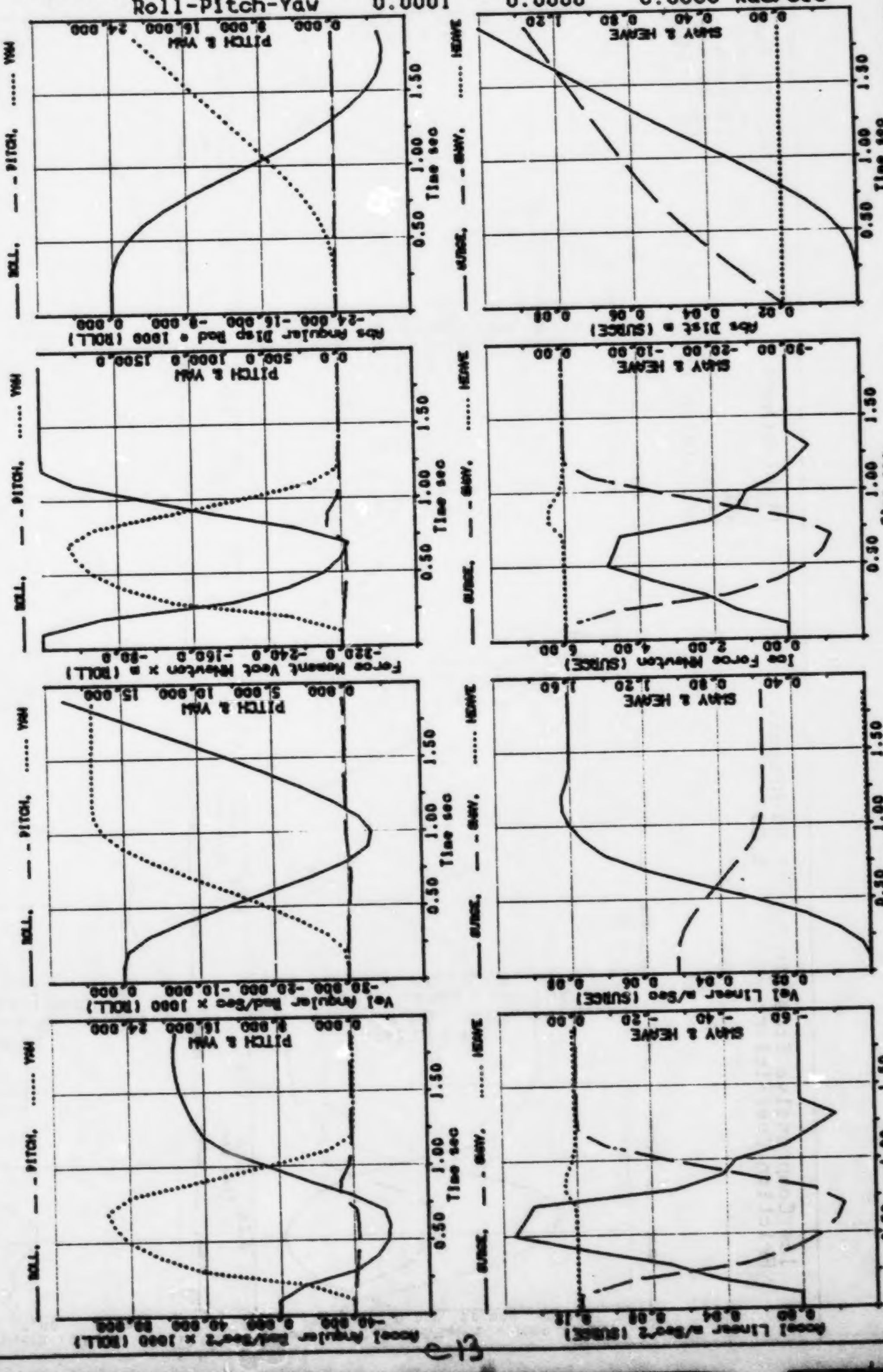
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Wed Nov 14-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Twin 6.0 M Nozzles
Side Inpact to Vetical Surface

Inital Velocity X-Y-Z	0.00	1.03	0.00	m/Sec
Roll-Pitch-Yaw	0.0001	0.0000	0.0000	Rad/Sec

Displacement	31411.5	Tonnes
LCG	-.59	m
VCG	13.00	m
Draft	12.00	m
Propulsion Power	0.0	kWatt
Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



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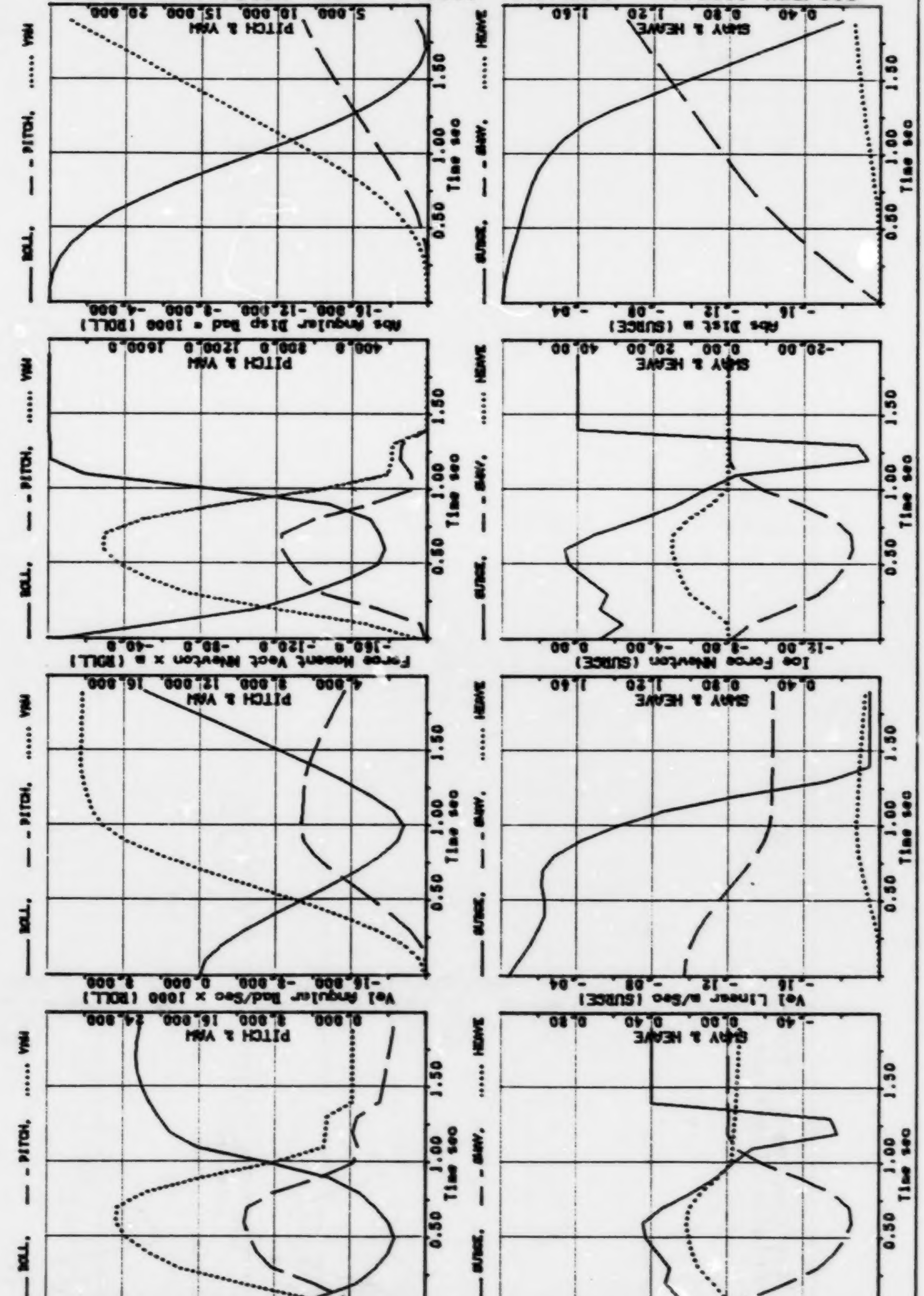
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Wed Nov 14-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Twin 6.0 M Nozzles
Side Impact to 30 Deg. Inclined Surface

Inital Velocity X-Y-Z	-.00	1.03	0.00	m/Sec
Roll-Pitch-Yaw	-.0001	0.0000	0.0001	Rad/Sec

Displacement	31411.5	Tonnes
LCG	-.59	m
VCG	13.00	m
Draft	12.00	m
Propulsion Power	0.0	kWatt
Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



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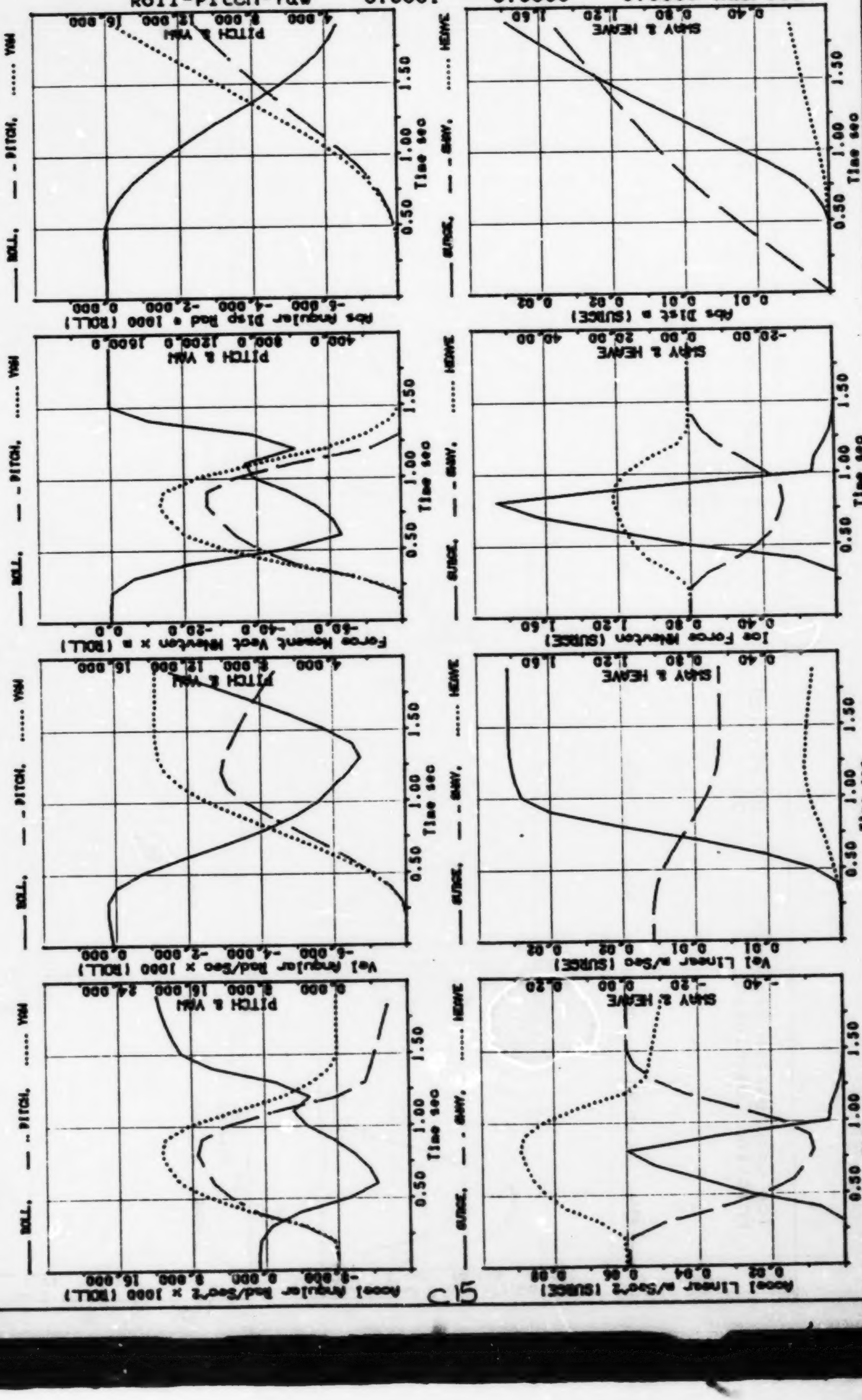
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Wed Nov 14-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Twin 6.0 M Nozzles
Side Impact to 60 Deg. Inclined Surface

Inital Velocity X-Y-Z	0.00	1.03	0.00	m/Sec
Roll-Pitch-Yaw	0.0001	0.0000	0.0000	Rad/Sec

Displacement	31411.5	Tonnes
LCG	-.59	m
VCG	13.00	m
Draft	12.00	m
Propulsion Power	0.0	kWatt
Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



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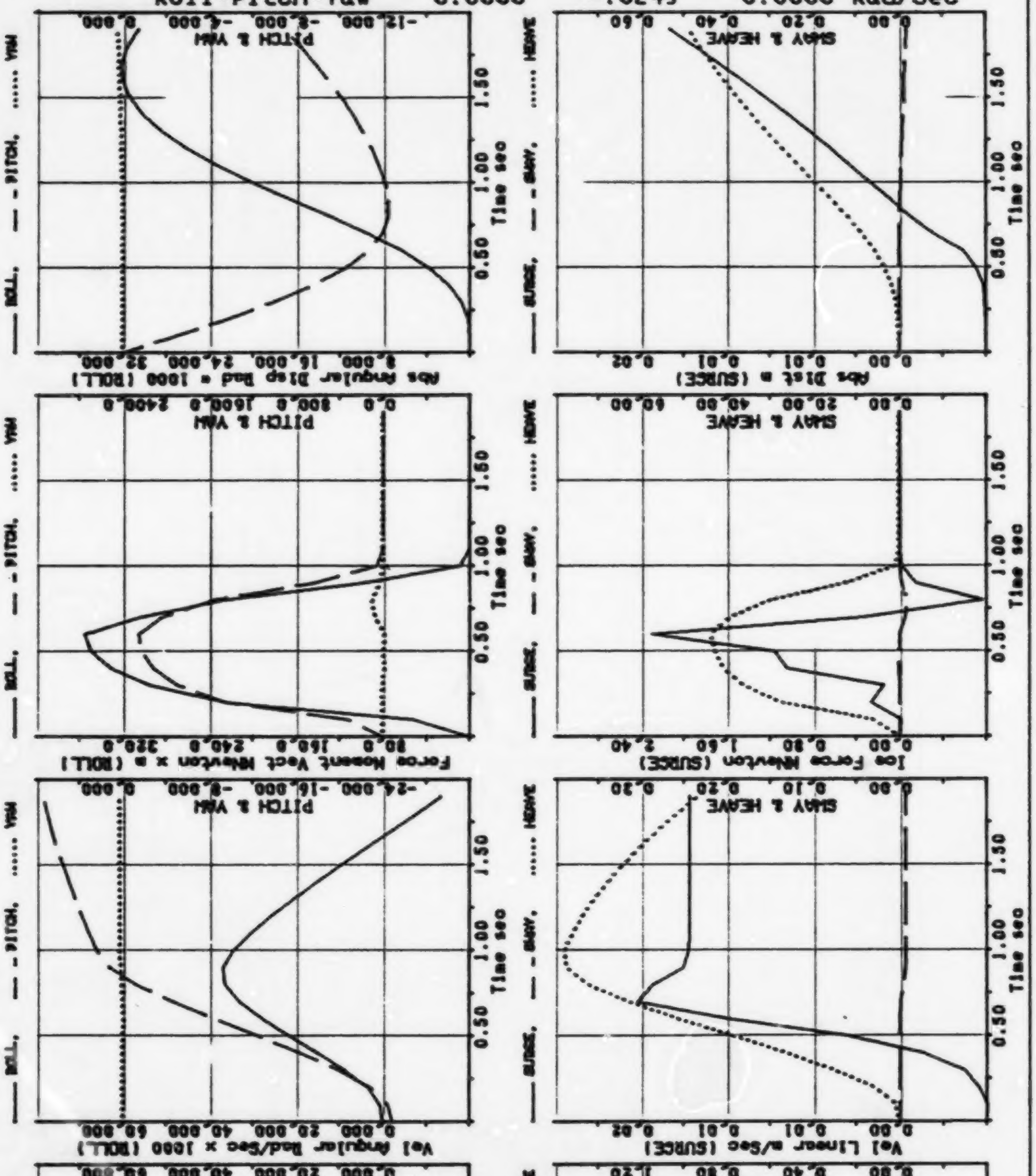
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Thu Nov 15-84

Dome Petroleum Ltd.
30000 T Displ't, 50000 HP Icebreaker
Twin 6.0 M Nozzles
Bottom Impact

Inital Velocity X-Y-Z	0.00	0.00	0.00	m/Sec
Roll-Pitch-Yaw	0.0000	-.0249	0.0000	Rad/Sec

Displacement	31411.5	Tonnes
LCG	-.59	m
VCG	13.00	m
Draft	12.00	m
Propulsion Power	0.0	kWatt
Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



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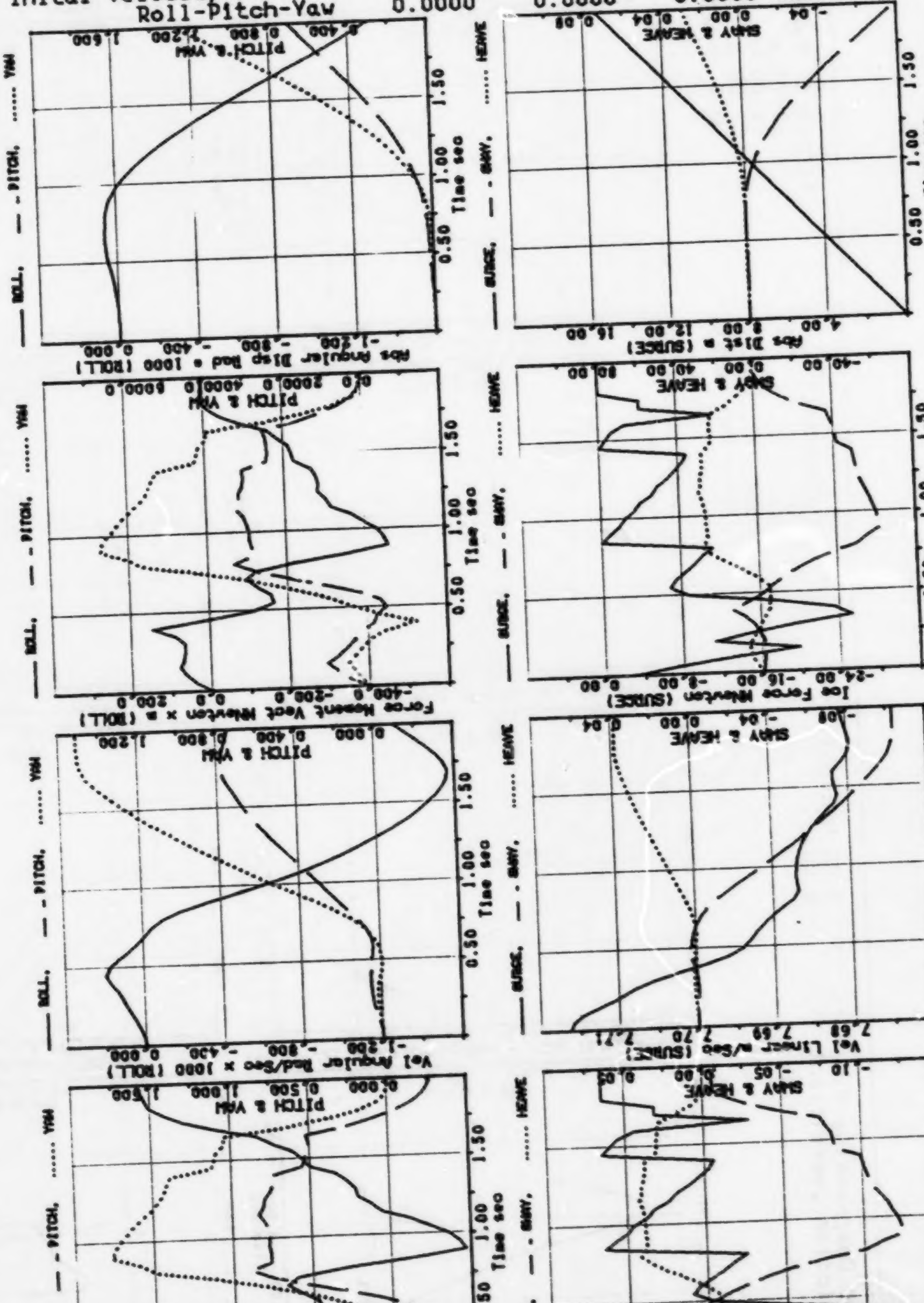
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Fri Nov 16-84

Dome Petroleum Ltd.
300,000 Tonnes Displ't, 2 x 50000 HP Tanker
Twin 8.0 M Nozzles
Head on Impact

Inital Velocity X-Y-Z	7.72	0.00	0.00	m/Sec
Roll-Pitch-Yaw	0.0000	0.0000	0.0000	Rad/Sec

Displacement	310390.9	Tonnes
LCG	-2.25	m
VCG	19.00	m
Draft	23.00	m
Propulsion Power	74600.0	kWatt
Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



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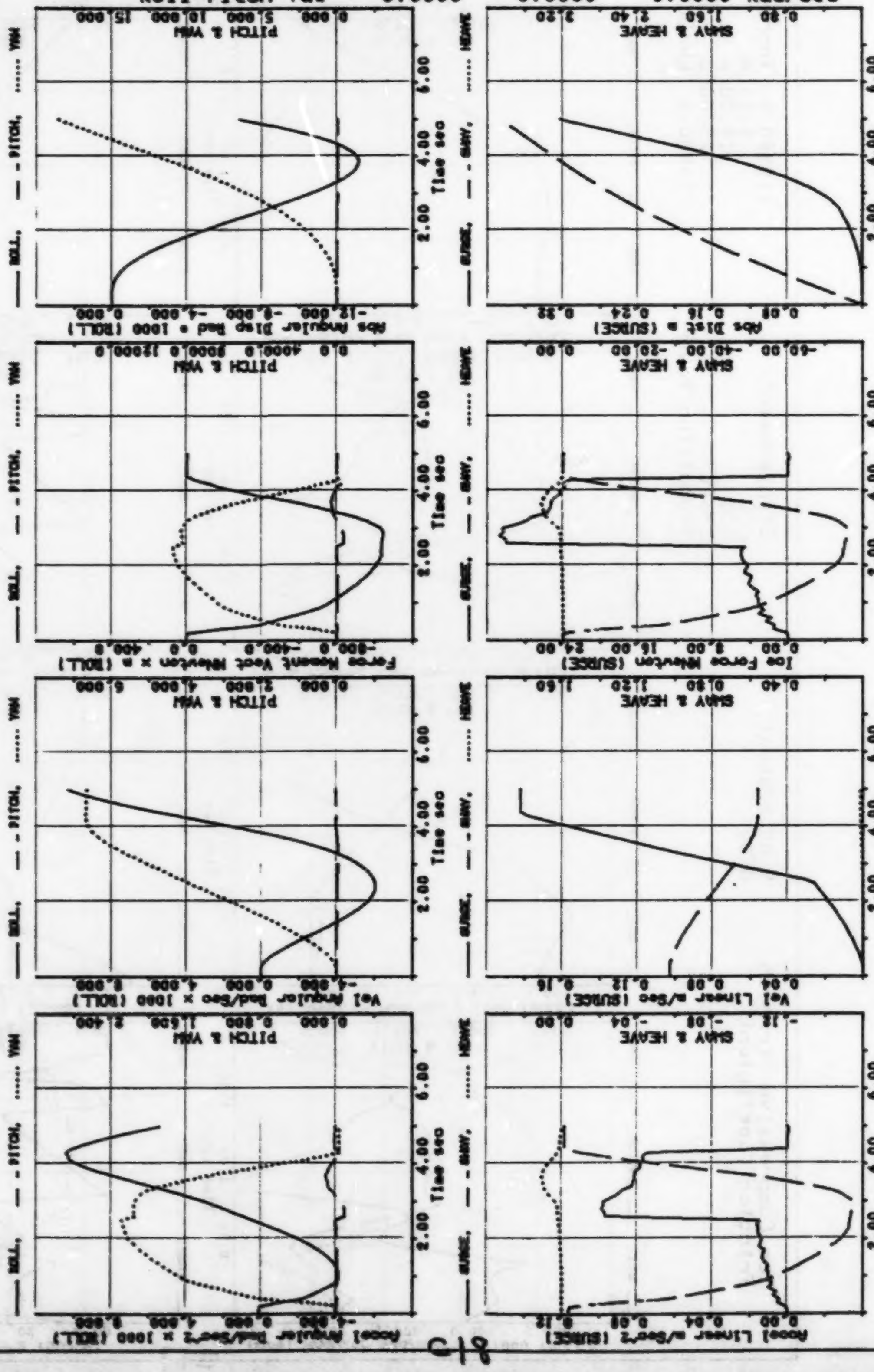
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Fri Nov 16-84

Dome Petroleum Ltd.
300,000 Tonnes Displ't, 2 x 50000 HP Tanker
Twin 8.0 M Nozzles
Side Impact to Vertical Surface

Inital Velocity X-Y-Z	0.00	1.03	0.00	m/Sec
Roll-Pitch-Yaw	0.0000	0.0000	0.0000	Rad/Sec

Displacement	310390.9	Tonnes
LCG	-2.25	m
VCG	19.00	m
Draft	23.00	m
Propulsion Power	0.0	kWatt

Ice Compressive Strength	5.00	MPascal
Friction Coefficient	0.00	



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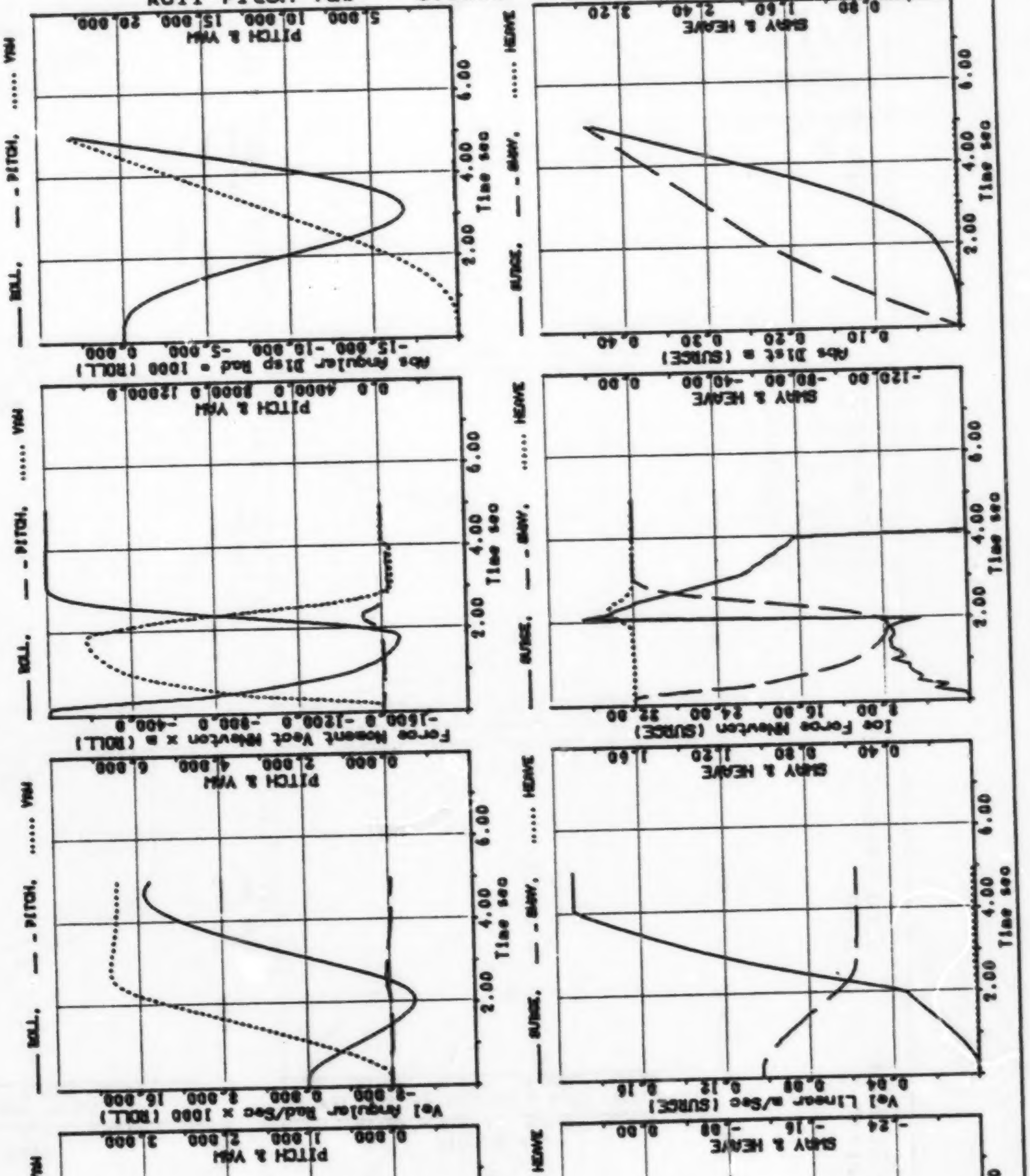
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Fri Nov 16-84

Dome Petroleum Ltd.
300,000 Tonnes Displ't, 2 x 50000 HP Tanker
Twin 8.0 M Nozzles
Side Impact to Vertical Surface

Inital Velocity X-Y-Z	0.00	1.03	0.00	m/Sec
Roll-Pitch-Yaw	0.0000	0.0000	0.0000	Rad/Sec

Displacement	310390.9	Tonnes
LCG	-2.25	m
VCG	19.00	m
Draft	23.00	m
Propulsion Power	0.0	kWatt

Ice Compressive Strength	10.00	MPascal
Friction Coefficient	0.00	



E19

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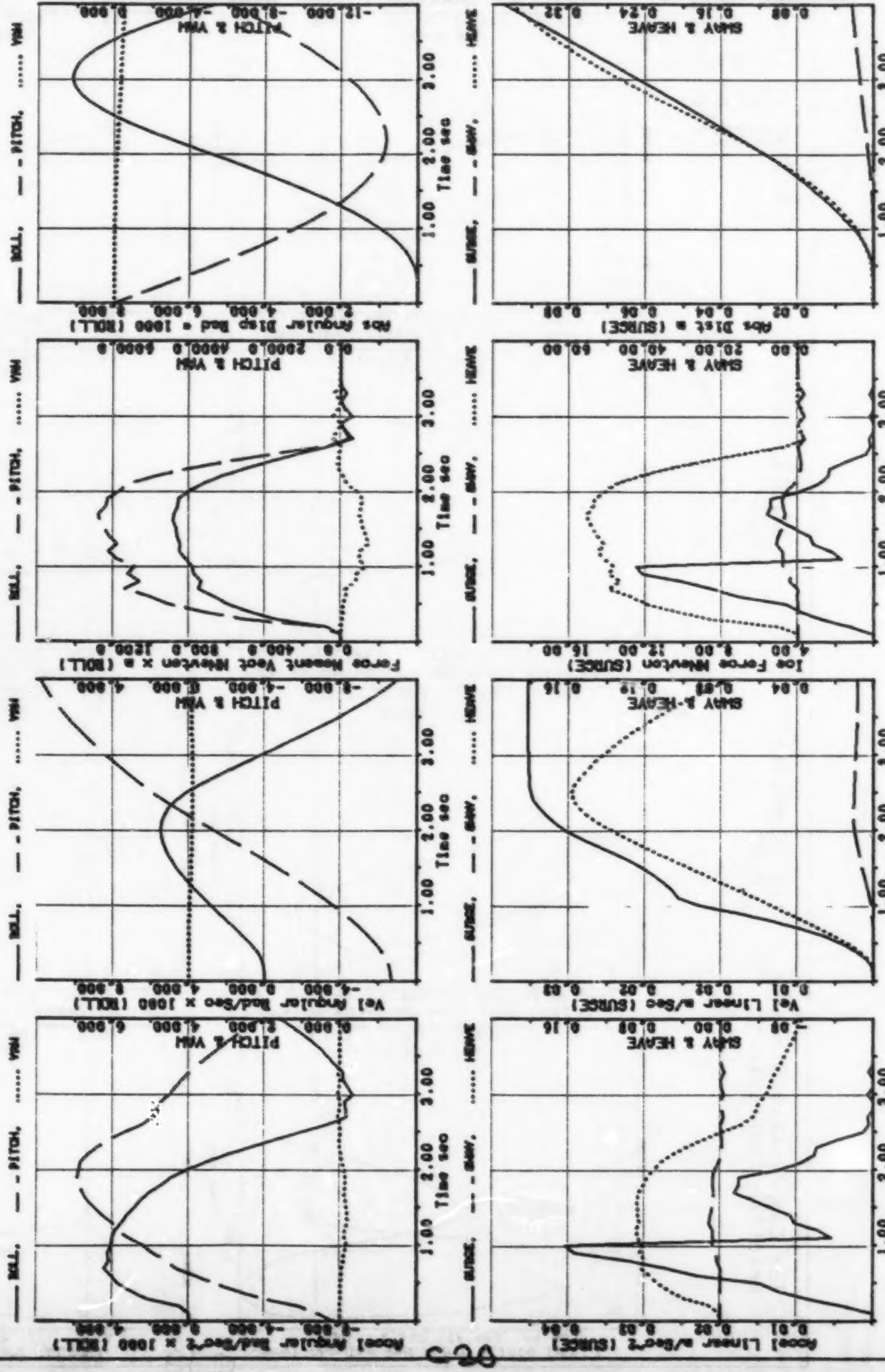
NautiCAN Research & Development Ltd.
111-3700 Gilmore Way, Burnaby B.C.
Tel (604) 437-4781 V5G 4M1
Project No.421 Thu Nov 15-84

Dome Petroleum Ltd.
300,000 Tonnes Displ't, 2 x 50000 HP Tanker
Twin 8.0 M Nozzles
Bottom Impact
Inital Velocity X-Y-Z 0.00 0.00 0.00 m/Sec
Roll-Pitch-Yaw 0.0000 -.0107 0.0000 Rad/Sec

Displacement 310390.9 Tonnes
LCG -2.25 m
VCG 19.00 m
Draft 23.00 m
Propulsion Power 0.0 kWatt

Ice Compressive Strength 5.00 MPascal
Friction Coefficient 0.00



C-20

APPENDIX D

A BRIEF INVESTIGATION OF NOZZLE PROFILE'S THICKNESS INFLUENCE ON THE HYDRODYNAMIC EFFICIENCY OF PROPELLER/NOZZLE SYSTEM

It is obvious that the magnitude of the ice induced loads assessed through the computer simulation is higher than the "ordinary", i.e. non-ice strengthened nozzle could withstand. A rigorous proof of this statement is contained in Chapter 9.0 of the Main Report.

In order to bring an "ordinary" nozzle to a higher strength standard, a designer has to investigate the simplified expression for a section modulus of the nozzle's profile:

$$SM = A_{pL} \times s$$

where A_{pL} is the cross section area of the outer plating ($A_{pL} = \ell \times t_{pL}$), and s is the average profile height ($s = s/l \times l$).

Thus two options are available to the designer:

- an increase of outer/inner plating thickness without changes of profile's geometry and/or
- an increase of profile's thickness s, which leads to a possible alteration of nozzle's hydrodynamic performance.

The second option seems more attractive as it does not require as much additional material to be used.

We therefore have to investigate this option in some detail before recommending it (or otherwise) to a designer.

A change of the nozzle's profile thickness has the following hydrodynamic implications:

CHANGE	CONSEQUENCE
Intake Profile Lengthening	Increase of bollard thrust, increase of drag at high speed.
Exhaust Profile Lengthening	Increase of drag ahead, increase of astern pull.
Increasing the Thickness of the Profile	Increase of nozzle drag.
Decreasing profile chamber	Nozzle thrust is less sensitive to change of ship speed and propeller loading.

These changes are visible while comparing two nozzles, 19A and 37 which differ substantially in thickness/length ratio (0.15 and 0.19 respectively), and in the profile shape, as illustrated in Table D.1.

There are two ways of increasing the thickness of the profiles:

- By enlarging the duct without changing S/1 ratio (ie "blowing-up" the profile), and

- By increasing the profile thickness and altering its shape.

Both of these methods lead to the increase of the surface area, and, consequently, of the drag. We will discuss them in detail.

TABLE D.1

COMPARISON OF TWO NOZZLES WORKING WITH Ka-4-70 Propellers

NOZZLE

NSMB#

	19A					37				
P/D	$(KTN)_o$ 1	$(K_T)_o$ 2	J_o 3	$(K_Q)_o$ 4	$K_Q(Jo)$ 5	(KTN)o	$K_T(o)$	J_o	$K_Q(o)$	$K_Q(To)$
0.6	.11	.23	.4	.016	.011	.11	.23	.40	.01	0.010
0.8	.18	.37	.53	.027	.017	.18	.37	.54	.027	0.014
1.0	.27	.52	.67	.044	.028	.27	.52	.67	.044	0.021
1.2	.36	.65	.79	.067	.042	.36	.68	.79	.065	0.030
1.4	.44	.87	.89	.093	.060	.44	.84	.91	.091	0.042

Notes:

1. Thrust coefficient (KTN) of the nozzle only, at bollard.
2. Thrust coefficient (K_T) of the system, at bollard.
3. Advance coefficient at 0 thrust of the nozzle.
4. Torque coefficient of the system, at bollard.
5. Torque coefficient of the system at 0 nozzle thrust.

P/D Is the pitch/diameter ratio.

INCREASE OF THE NOZZLE'S SURFACE AREA DUE TO THE INCREASE OF NOZZLE'S PROFILE.

We have, for $\ell/D = 0.5$

s/l	.15	.2	.25
$\frac{A_{tot}}{2\pi D^2}$	.612	.650	.690
% Change	0	6%	12%

Thus for each 0.05 increment in s/ℓ ratio, there is 6% increase in the total nozzle's area.

INCREASE OF THE NOZZLE'S SURFACE AREA DUE TO ELONGATION OF THE NOZZLE (WITHOUT CHANGING NOZZLE PROFILE CHARACTERISTICS).

On the assumption that nozzle's inner diameter does not change, we have:

Internal Surface Area $A_{INT} = \pi \ell D$

External Surface Area $A_{EXT} = \pi \ell (D + 2s)$

Transverse Surface Area $A_{TR} = 2 \times [(D+2s)^2 - D^2]/4$

Total Surface Area = $A_{TOT} \cong 2\pi Dl (1 + s/\ell) * (\ell/D + 1)$

or, for computations' sake:

$$A_{TOT}/2\pi D^2 = \ell/D (1 + s/\ell * (\ell/D + 1))$$

Right hand values of the above equation are given below.

ℓ/D	0.5	.6	.7	.8	.9	.10
s/ℓ						
.15	.612	.44	.878	1.016	1.15	1.30
.20	.650	.792	.938	1.09	1.24	1.40
.25	.690	.840	1.00	1.16	1.33	1.50

Examination of this table reveals that the growth of the total surface area is roughly proportional to the growth of the length of the nozzle, ie.

$dA_{TOT} \approx c.d(\ell/D)$

SECTION MODULUS CALCULATIONS

The section modulus of the nozzle can be expressed as:

$$SM = s \times A_{PLG} = S \times \ell \times t_{PLG}$$

On the assumption of having thickness of the plating constant (as dictated by local strength requirements), we will have

SM for a thickness increase thru the lengthening of the nozzle:

$$\frac{SM}{t_{PLG}\ D^2} = s/\ell \times (\ell/D)^2 \quad \text{where } \ell/D \text{ varies.}$$

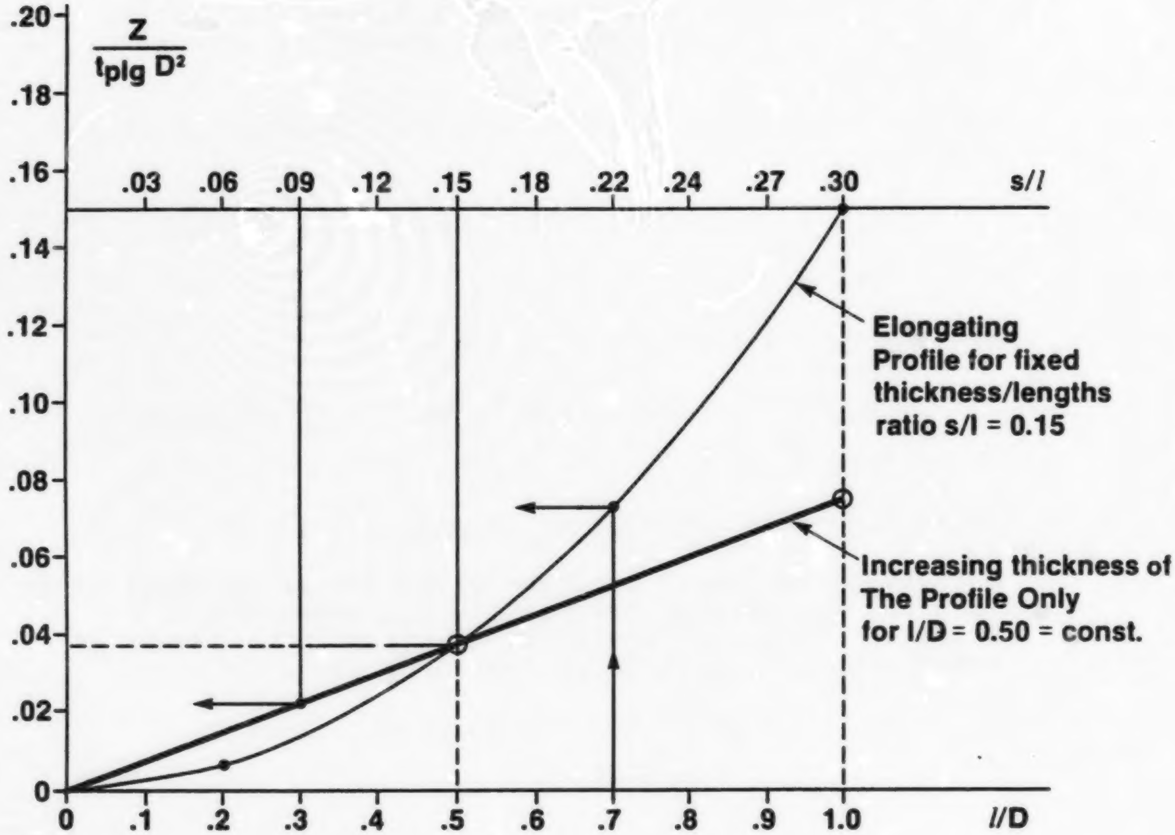
and the SM for thickness increase only.

$$\frac{SM}{t_{PLG}\ D^2} = s/\ell \times (\ell/D)^2 \quad \text{where } s/\ell \text{ varies.}$$

These functions are plotted in Figure D.1.

Note that the length increase gives faster increase of SM then the increase of the profile thickness alone. However, if we take the ratio of strength to amount of material used, which is reflected by ratio.

$$\eta = \frac{SM}{t_{pg}\ A_{surf}}$$ then we will find



CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Section Modulus As A Function of s/*l* and *l*/D
		FIGURE No. D-1

that the efficiency of material is higher when we increase the thickness the profile without altering its length. Values of η are given below.

	ℓ/D			
s/ℓ	.5	.6	.7	.8
.15	.061	.072	.084	.094
.20	.077	.091	.104	.177
.25	.091	.107	.123	.138
.30	.103	.122	.139	.156

INFLUENCE OF THE PROFILE THICKNESS ON THE DRAG OF THE NOZZLE.

There are two main sources of a drag of the nozzle:

Frictional drag and pressure (form) drag.

Usually, both drags are lumped together to form so called total drag expressed by the equation:

$$\text{Drag} = C_D \, \rho V^2 * A/2$$

where:

A = is the nozzle's reference surface ($A = \pi D l$)
V = is the effective speed of water flow around the nozzle
ρ = is water mass density
C_D = is the non-dimensional drag coefficient

We will start our calculations of the drag by assessing the water flow velocity around the nozzle.

VELOCITY OF WATER FLOW AROUND THE NOZZLE

Take an "ideal" nozzle - propeller system, developing a given thrust T. "Ideal" refers to a frictionless propeller/nozzle system.

Using momentum theory the speed of water in the propeller disk is:

$$V_{prop} = (V_{ship} + (V_{ship}^2 + 2T/\rho A_{prop})^{1/2})/2$$

Taking Canmar Kigoriak, for example, we obtain

V [m/s]	0	4	8
T [kN]	1790	1350	1000
V_{prop} [m/s]	6.22	7.77	10.14
V_{av} [m/s]	4.4	6.2	9.1

An average speed (V_{av}) of the water is the average of the inside of the nozzle and exterior water speed , i.e.:

$$Vav \cong (V_{prop}^2 + V_{ship}^2)/2)^{1/2}$$

It is noted that V_{prop} is significantly higher then that of the ship.

Reynold's number for the nozzle is calculated as:

$$Re_1 = V_{av} . \ell/D . D/\nu$$

which is analogous to the Reynold's number for the two dimensional flow.

Setting kinematic viscosity of water at 1.7810^{-6} m^2/s and ℓ/D at 0.5, we obtain:

$$Re_1 = 2.81\ 10^5 \times V_{av} \times D$$

For the moderately large nozzles ($D \sim 5m$) and $V_{av} > 0.2$ m/s, we can safely assume that $Re_1 > 10^6$ and the flow of water is always a turbulent one.

DRAG COEFFICIENT

Using the method developed by Van Manen we can calculate the nozzle's drag coefficient at small angles of attack as follows:

$C_{DN} = 2\ c_f\ (1 + 2\ (s/\ell)^2)$, where c_f is defined as

$$c_f = 0.455/(\log Re)^{2.58}$$

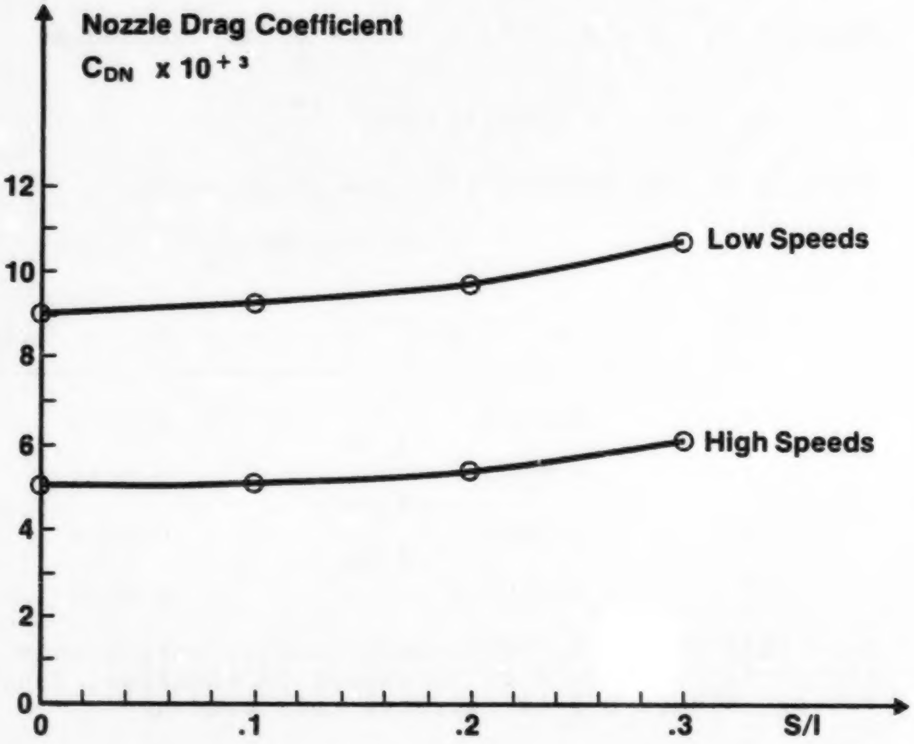
Results of the computations are given below:

VALUES OF C_{DN}

s/ℓ	Re = 1.10^6		Re = 3.10^7	
0	0.0090		0.0050	
		+2.2%		+2%
.1	0.0092		0.0051	
		+5.4%		+5.9%
.2	0.0097		0.0054	
		+9.3%		+11.0%
.3	0.0106		0.0060	

Note that the drag coefficient changes very little (less than 10%) for each 0.05 increment in thickness/length ratio. Figure D.2 illustrates this tendency.

Above values are approximately twice those of ship hulls. It is so because when calculating ship's frictional drag we use total wetted surface area, while calculating nozzle's drag we use only half of total area ($A = \pi Dl$).



CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Nozzle Drag Coefficient For Small Angles Of Attack FIGURE No. D-2

TOTAL DRAG CALCULATIONS*
DRAG IN NEWTONS

V		D = 5 m			D = 10 m		
m/S	s/l	.15	.20	.25	.15	.20	.25
5		1981	2015	2058	4791	4873	4978
7.5		3282	3338	3410	8358	8501	8685
10		4790	4873	4978	12581	12796	13073

* Using Formulation:

$$D_{Nozzle} = 7.357 \times (1+2(s/\ell)^2)D^2V^2/(\log(\frac{\underline{VxD}}{D}))^{2.58}$$

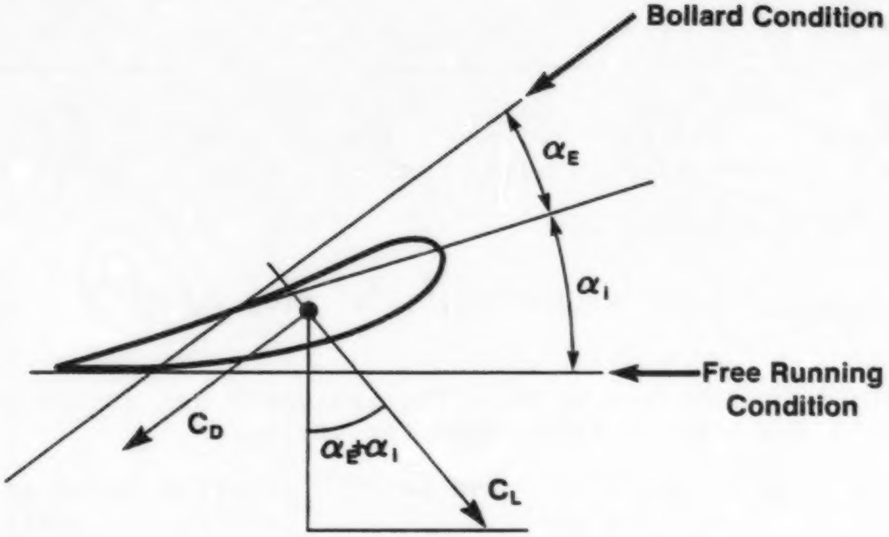
which is obtained by substituting Van Manen's formulas into the general expression for the drag.

The drag of the nozzle can be also assessed in terms of the profile drag, since the nozzle profile is composed of streamline profiles. To calculate profile's drag, an angle of inflow of the water against the nozzle's reference line must be known. Figure D-3 shows the force and vector velocity diagrams.

Using NACA 4415 as an example, we will obtain, for the bollard condition.

$C_T = 1.4 \sin (12° + 12.5°) - 0.020 \cos (12° + 12.5°) = 0.628$

Note that CD/CL = 0.014


Bollard Condition
α_E
α_i
Free Running Condition
C_D
$\alpha_E + \alpha_i$
C_L

Thrust Coefficient Of The Nozzle is
$C_T = C_L \,\mathrm{SIN}\,(\alpha_E + \alpha_i) - C_D \,\mathrm{COS}\,(\alpha_E + \alpha_i)$

For The Bollard Condition $C_L = C_L$ Max
Stipulates That $\alpha_E = \pm 12^\circ$

For Free Running Condition $\alpha_E = -\alpha_i$

CANADIAN MARINE DRILLING LIMITED	Strength Requirements For Nozzles For Ice Transiting Ships	TITLE: Nozzle Force Diagram FIGURE No. D-3

For the free running condition ($\alpha_E = -\alpha_i$)

$C_T = -0.8 \sin (12.5 - 12.5) - 0.013 \cos (12.5 - 12.5) =$
-0.013

It should be noted that at the bollard condition the drag coefficient is 2.8% of the lift coefficient (or 29% of the thrust coefficient) while at free running it is 100%.

For the free running condition, we will investigate the profile thickness influence on drag for a series of NACA profiles ($\alpha_E = -12.5°$)

NACA	4415	$C_L =$	-0.90	$C_D =$	0.0135
	4418		-0.85		0.0130
	4421		-0.80		0.0130

This comparison shows slight decrease of the drag coefficient with increased thickness. Note however that lift coefficient decreases significantly.

As an approximation we can use the following values for the drag coefficient.

Bollard	Free Running
0.018	0.013

Computations for the actual ship (Canmar Kigoriak) are performed as follows:

V [m/s]	0	4	8
Thrust [kN]	1790	1350	1000
V_{AV} [m/s]	4.4	6.2	9.1
C_D	0.018	0.015	0.013
Drag [kN]^1	8.0	13.3	24.8
Drag/Thrust [%]	0.4%	1%	2.5%

Note 1: Using formula $D = 1/2\ \rho\ V_{AV}{}^2\ \pi D^2\ \ell/d$

with $\rho = 1025\ kg/m^3$, $D = 5.35\ m$, $\ell/D \doteq 0.5$ which translates into

$D = C_D \times 23\ V_{AV}{}^2$

Thus friction drag represents only a few percent of the total thrust.

In terms of the percentage of the nozzle's total thrust we will calculate the drag as follows:

Assuming that MV Kigoriak's nozzle is equivalent to NSMB #37, we will have:

V [m/s]	0	4	8
K_{TN} [-]	0.22	0.12	0.075
T_N [kN]	929	507	317
Drag/Thrust of nozzle %	.9	2.6	7.8

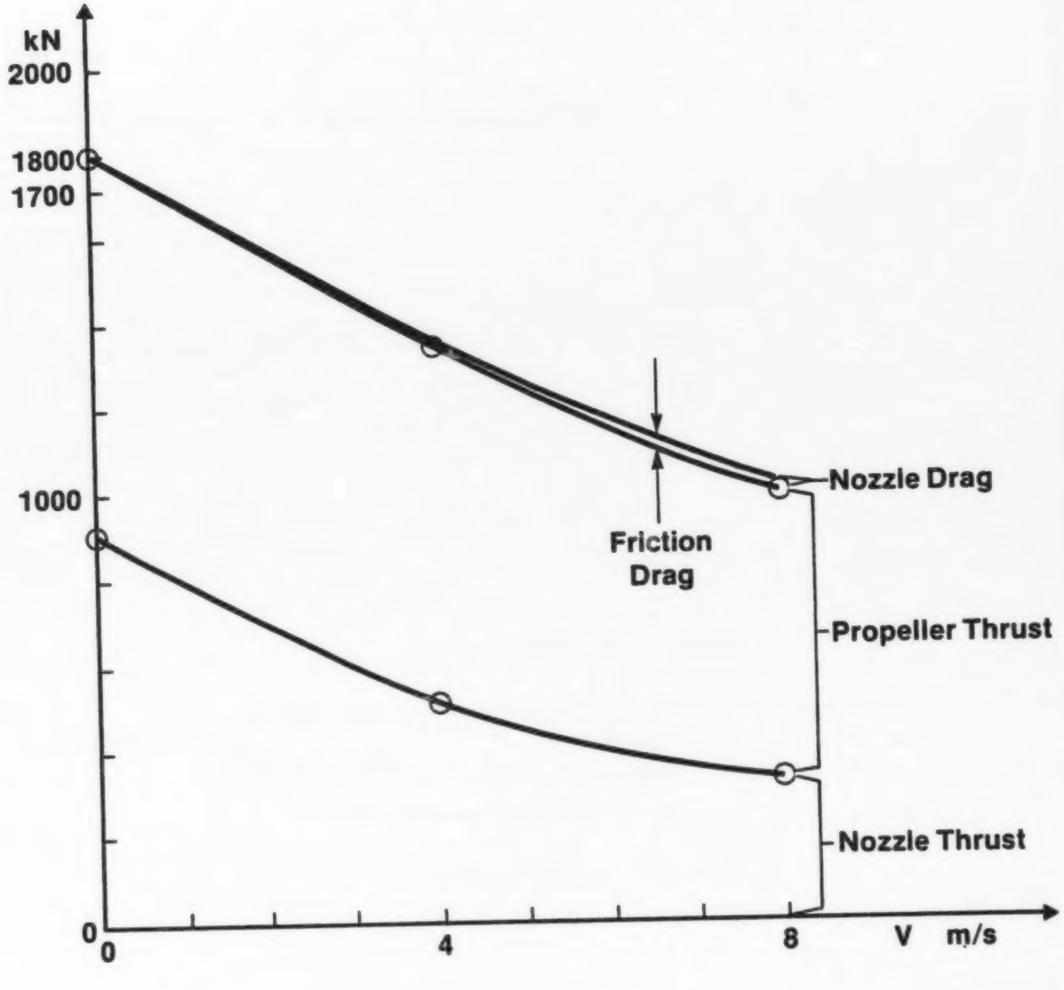
Values from this table and the table above are plotted on Figure D-4.

Separation

The flow of water inside of the nozzle (slipstream) will separate from the wall of the nozzle when the angle of divergence α_{exit} will exceed 3°.

This separation, which is unavoidable for the nozzles of the NSMB #37 type (i.e. having good astern characteristics) should increase the drag.

A comparison of the nozzles 19A and 37, does not show such a tendency. This is probably because of the fact, that at bollard condition, separation does not increase the drag, as the water is stagnant around the nozzle. At high speeds, internal separation of the slipstream in the nozzle 37 is compensated by external separation on nozzle 19A which has a larger angle of attack d_i. See Figure D-5.

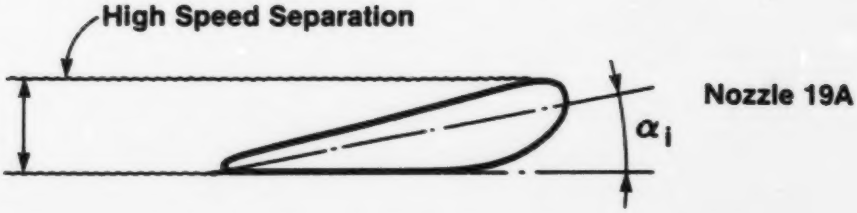


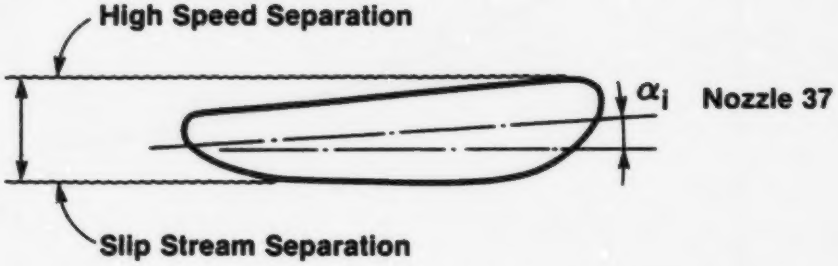
CANADIAN MARINE DRILLING LIMITED

Strength Requirements For Nozzles For Ice Transiting Ships

TITLE: Thrust Curves As A Function Of The Ship's Velocity For MV Kigoriak

FIGURE No. D-4


High Speed Separation
α_i
Nozzle 19A


High Speed Separation
α_i
Nozzle 37
Slip Stream Separation

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Strength Requirements
For Nozzles For Ice
Transiting Ships

TITLE: Flow Separation Around The Nozzle

FIGURE No. D-5

Drag Increase Analysis

Total drag increase is a sum of the profile drag increase and surface drag increase:

$$\text{Drag} = 1/2\ C_D \times \rho V^2 \times A$$

Differentiating, we will have:

$$\partial(\text{drag}) = (\partial \text{drag}/\partial C_D)\ dC_d + \partial \text{drag}/\partial A\ dA$$

Substituting for C_D

$$C_D = 2C_f\ (1 + 2(2s/\ell)^2)$$

$$\partial CD/\partial(s/1) = 2C_f \times 4(s/\ell)$$

$$dC_D = 8\ C_f\ (s/\ell) \times d\ s/\ell$$

$$dC_D/C_D = 4\ (s/\ell)/(1 + 2(s/\ell)^2)\ d\ (s/\ell)$$

Substituting for A

$$A = 2\pi D^2 \times 1/D\ (1 + s/\ell\ (\ell/D + 1))$$

$$dA = \partial A/\partial(1/D)\ d(\ell/D) + \partial A/\partial(S/\ell)\ d\ (S/\ell)$$

$$\begin{aligned}\partial A/\partial(1/D) &= 2\pi D^2[(1+s/\ell\ (\ell/D+1)) + (\ell/D)(S/\ell)] \\ &= 2\pi D^2(1+S/\ell\ .\ (2\ell/D+1))\end{aligned}$$

$$\partial A/\partial(S/1) = 2\pi D^2(\ell/D)(\ell/D + 1)$$

$$dA = 2\pi D^2\ [1 + S/\ell\ .\ (2\ell/D + 1)\ d(\ell/D) + \ell/D\ (\ell/D+1)\ d(S/\ell)]$$

$$dA/A = [1+s/\ell\ (2\ell/D + 1)].d(\ell/D) + \ell/D(\ell/D+1).d(s/\ell)]\ /(\ell/D(1+s/\ell(\ell/D+1)))$$

Now restructuring first equation:

$$d(\text{drag}) = 1/2\ \rho v^2 A\ dC_D + 1/2\ \rho v^2 C_D\ dA$$

$$d(\text{drag})/\text{drag} = dC_D/C_D + dA/A$$

and substituting

$$d(\text{drag})/\text{drag} = 4\ (s/\ell)/(1 + 2\ (s/\ell)^2)\ .d(s/\ell + [1 + s/\ell(2\ell/D + 1)]\ .d(1/D) + \ell/D(\ell/D + 1)\ .d(s/\ell)]/\ell/D\ (1 + s/\ell(\ell/D + 1)$$

we will take basic nozzle as having $s/1 = 0.15$, $\ell/D = .5$.

then, putting numbers in, we will get:

$$d(\text{drag})/\text{drag} = .574\ d(s/\ell) + 2.12\ d(\ell/D) + 1.22\ s/\ell, \text{ or}$$
$$d(\text{drag})/\text{drag} = 1.8\ d(s/\ell) + 2.12\ d(\ell/D)$$

Values of $d_{\text{drag}}/\text{drag}$ are tabulated below:

	[d(s/ℓ)]					
d(ℓ/D)	0	.05	.10	.15	.2	.25
0.0	0.00	0.09	0.18	0.27	0.36	0.45
0.1	0.21	0.30	0.39	0.48	0.57	0.66
0.2	0.42	0.51	0.60	0.69	0.78	0.87
0.3	0.64	0.73	0.82	0.91	1.00	1.09
0.4	0.85	0.94	1.03	1.12	1.21	1.30
0.5	1.06	1.15	1.24	1.33	1.42	1.51

To conclude this investigation, we can state that:

- Nozzle drag is increased by increasing nozzle profile thickness.
- Nozzle's drag is a small percentage of the total thrust of nozzle/propeller system.
- Change in the nozzle's thickness within reasonable range ($0.15 < s/\ell < 0.3$) does not affect total thrust of the system significantly and therefore it can be recommended as one of the means of increasing the strength of the nozzle.